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ORIGIN AND DEVELOPMENT OF CRATERS

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ABSTRACT

This book records the author's experience in measuring physical processes at Hawaiian craters and in mapping changes at the craters themselves.

Parts 1 and 3 are hitherto unpublished diaries of 1912–1913 and May 1924 at Kilauea Crater. Part 2 is a condensation of 26 years of Hawaiian volcano observations and experiments. Parts 4 and 5 are map studies of crater evolution. Part 6 is a review of crater classification and theory of magma, and the author's geologic conclusions. Part 7 is a summary, with suggestions on earth structure, and the seismology, physics, and chemistry of volcanism, mainly limited to magma.

The motive governing the assemblage of observations, maps, sections, diagrams, curves, photographs, reviews, and narrative histories in this discussion of craters is to model a statement for the first half of the twentieth century outlining the field volcano science that has grown up since James Dwight Dana published his *Characteristics of volcanoes* in 1891.

Like that work this one is based on Hawaiian experience, with the method of permanent observatory work supplanting Dana's excellent but partly vicarious recording. This has permitted more continuity than was possible to Dana, but it is likewise one man's work studying volcanoes for half a century. Crater changes were the main interest of Professor Dana. That therefore is a reasonable theme whereon to base a new approach to field volcanology. Geophysics is growing and is the author's main interest. He is frankly imaginative, radical, and experimental in his outlook. His model in scepticism was Clarence Edward Dutton, who made mistakes also, but none the less laid foundations whereon to build.

The word crater is not used in any limited sense, and the title of the book follows the precedent of many authors, including Dana, in generalizing from Hawaii. The title places action before structure. Hawaii is typical of primitive process of crater development. Geographical and lunar processes of comparative volcanology are repeatedly referred to. In contrast to some geologists the author is guided by conviction from experience that volcanic action is alternately magmatic and phreatic. Hawaiian craters illustrate both processes. Tumefaction and engulfment alternate. The first is magmatic, the second is structural break-down admitting water. Any theory based on an open conduit is to the author inconceivable for a crusted globe restraining sun matter in its core.

INTRODUCTION

DESCRIPTION OF THE PARTS

The separate parts of this Memoir exhibit the evolution of craters, in the light of modern volcanology, as expressed by the twentieth-century activities of Kilauea Crater as a type vent. Historical and theoretical considerations are discussed in Part 6. The plates carry rather full descriptions so that they might serve as a graphic narrative as well as to supplement the text.

Part 1, Kilauea Crater in 1912–1913, introduces the reader to the detail of observations at the newly founded volcano observatory. Most of the principles of crater origin and development illustrated in this Memoir came to attention during that first year, and experimental development of instruments for surveying, photography, and seismology as applied to volcanoes became a vital problem. Those in charge of the Observatory were cognizant of the notion of cycles and the difficulties of gas chemistry, of temperature measurement, of correlation with meteorology, and of publication suitably financed and illustrated. The same serious difficulty of maintaining the public interest that has confronted the Vesuvian observatory, the conception of observational permanency independent of spectacular eruption, was encountered when the volcano became quiet in 1913 and has been an administrative obstacle in quiet times ever since. That a volcano is always producing measurable physical processes, like the moving stars, is a novel idea to most people.

Part 2 presents a narrative of volcanic events at all the Hawaiian craters and their extensions in rift cracks, from 1909 to 1935. The illustrations are mostly photographic, but Part 4 contains sketch maps of crater development. This narrative discusses the experimental measurements, adventures in gas collection, and other matters of method to show how the volcanic events influenced the scientific work. The chapter closes with a summary, with references to diagrams, showing the rising and falling of lava during 26 years in the several craters of a single volcanic system.

Part 3, like Part 1, supplements the documents already published (Bulletin and Volcano Letter, Hawaiian Volcano Observatory), concerning a single year of routine. Several descriptions have been published about the explosive eruption of Kilauea in May 1924. Mr. R. H. Finch, in charge of the Observatory, assisted by Mr. Oliver Emerson, secured a number of volunteer observers, who watched Kilauea night and day for 22 days. These minute-to-minute observations of the interior of an exploding crater, from a point 2 miles away, make an unusual scientific and human document, within which tragedy had its part. Here is summarized the evidence for correlation of tilt with tumescence and subsidence.

Part 4 discusses a selected sequence of maps and profiles of Halemaumau, to accompany the events recorded in Parts 1, 2, and 3. The maps for 1917 are shown in a sequence of four (Pl. 77), just as sequences are shown (Figs. 1–6) for 1912. For later dates sequences and single maps are reproduced, to illustrate the mass of detail in the Bulletin and the Volcano Letter from 1918 to 1934. There are many more maps in the Observatory files, and in the Bulletin of 1921 an attempt was made to publish monthly maps. This became impracticable when the pit collapsed and only occasional mapping was possible. This occasional mapping was incompletely published in the routine reports, but enough maps are reproduced to make a consistent sequence. The changes in the larger craters have been published elsewhere (Green, 1887; Dutton, 1884; Dana, 1891; Brigham, 1909; Hitchcock, 1911; Stearns, 1930; 1946; Stone, 1926b), and special photographic and other studies of the changing profiles of the Halemaumau crags await special publication. The attempt has been made in Part 4 to explain the sequence of profiles from 1917 to 1921 in language that will make more intelligible the relationship between aphrolith and dermolith (crag lava and lake lava) (Jaggar, 1917b) which is so difficult to understand except by actual observation of changing crater bottom.

Part 5, Hawaiian Crater Histories, lists references to excerpts from the Observatory publications about Kilauea and the other volcanoes including Mauna Loa, and various physical discussions are summarized.

Dana (1891), Hitchcock (1911), and Brigham (1909) wrote earlier histories. William Lowthian Green (1887) suggested a 9-year periodicity for the Hawaiian volcanic system, which our experience has modified to an 11-year cycle, owing to record over a much longer period. A diagram presented for this history (Pl. 86) applies to both Mauna Loa and Kilauea. This is followed by a brief discussion of the breakdown of the Hawaiian domes into amphitheaters and a comparison of Dana's discussion of Kilauea Crater and Mokuaweoweo with our own.

Part 6, Principles of Crater Evolution, reviews the studies of volcanic vents made in the nineteenth century by Shaler (1903), Pickering (1906), Judd (1881), Stübel (1903), Geikie (1903), and Suess (1906), and by more modern writers from Mercalli (1907) to Williams (1941b). Students looking for a discussion of modern volcanologic theory in relation to the history of science will find it in Chapter XI of *Vulkankunde* (Sapper, 1927, p. 356). Part 6 includes crateral physics and chemistry, and the writer's earlier speculations concerning the circular symmetry of some lines of volcanoes. He had been disposed to doubt that volcano steam blasts could be magmatic. Experience with gas collection and basaltic magma on the one hand, and the phreatic explosion of Kilauea on the other, confirmed his conviction that the driving force of volcanism is not solely steam, and the responsible gases are of dual origin—they are magmatic on the one hand and from contamination by surface water on the other. The real character of volcanism, as Joly (1926) has pointed out, is masked by the facts that most of it is submarine, submerged in water of its own production, and that most magmatic volcanism is submarine intrusion. To preserve unity the term volcanism should be limited to magma.

In Part 7, the writer takes the facts established and discusses magma, volatiles, and the structure of the mantle in relation to internal pressure and the deep gases and arrives at the complication that ensues when tension fracture of a volcanic system lowers magma by submarine outflow and admits ground water into hot voids. Observational volcanology cannot escape from seismology, and both indicate that under the bedrock of ocean bottom is solar matter whose hydrogen, carbon, nitrogen, and oxygen are the fundamental elements controlling outflow of energy.

PART 1—KILAUEA CRATER IN 1912-1913

GENERAL CONSIDERATIONS

The journal (Parts 1 and 3), based on daily notes on trips to the inner pit Halemaumau, will be more interesting to geologists who have not visited Hawaii if they understand the crater and its appearance. To Hawaiians Kilauea is the outer crater 3 miles across. Halemaumau, 1400 feet across in 1912, is a circular caldron of engulfment in an inner dome of nineteenth century lava. The surface of this dome appears as a flat floor to the casual traveller at the hotel on the northeast verge of the greater sink. This Kilauea floor was really flat about 1880, but voluminous overflowings of Halemaumau have built the pit rim 200 feet higher than the lower margins of the fill. Dana's *Characteristics of volcanoes* (1891), the best book on magmatic volcanology of the time, admirably describes the birth of Halemaumau.

The outer crater, Kilauea, aptly called by Daly (1911b) a "sink", is one of the "calderas" of post-Tertiary time, an ancient center of engulfment or recurrent lowering of lava at a central well, with or without steam-blast. The well of Kilauea is Halemaumau (Pls. 2a, 9), that of Halemaumau is a smaller concentric shaft under its own small floor and the bottom region of both is a dike or fissure that trends ENE-WSW, but bends to E-W where it crosses Kilauea. There is good evidence that this "Kilauea rift belt" is permanently full of upward-pressing lava. The well under Kilauea sink was created in the elliptical domes, outer and inner, when recession followed radial extrusion at the orifice along the rift that was originally largest. This opening was at the rift bend. Here the outer Kilauea dome built its summit. This summit was in former ages over the present sink. The highest flows from the ancient summit crater structurally form the crest of the high west cliff of Kilauea 4080 feet above sea. The period of maximum superfluence (to use Dana's word) was ages ago, and thereafter the top caved in. Such is Kilauea Crater.

In recurrent cycles within longer cycles, lava has risen within it, causing tumefaction of the crateral margins and filling partially the inner void. Such cycles of filling have been ended by episodes of engulfment and explosion. The last such explosion before 1912 was about 1790. The 1912 "floor" or inner dome was constructed of more than 1000 feet of heaped-up lava flows between 1790 and 1912. The walls in 1912 were less than a third as high as the maximum of 1825. They are in many places vertical, mostly 300 to 500 feet high, lowest at the south; the Observatory is at the top of the northeastern cliff, 2.1 miles from the Halemaumau edge and 280 feet above it.

Kilauea is a wooded plateau mountain, a spur of Mauna Loa, and not a steep cone like Vesuvius. The sink comes as a surprise after a drive from Hilo through tree-ferns. From one vantage point on the northeast it is seen as a big raw depression with stratified reddish lava walls and black floor, the pit in the distance, and, beyond, the Kau desert, transected by innumerable cracks of the rift surmounted locally by cones. Off to the left (east) other cracks, pits, and cones on the eastern bend of the rift extend 30 miles to the East Point of Hawaii, marked by many hot vaporing vents in forest.

Seaward to the southeast are fault steps in bluffs that mark breaks parallel to the Kilauea rift belt. The Crater fault is merely an upper member, and there are other block faults of similar trend higher on the Mauna Loa flank. All these fault blocks are breaking down and slipping seaward on the SSE side of the great Mauna Loa shield volcano.

At the top of Mauna Loa is a sink, Mokuaweoweo, on the Mauna Loa rift belt, duplicating Kilauea's with cracks trending and bending like the Kilauea rift. This is the uppermost break of the series, and the Mauna Loa fracture extends 25 miles from SW to NE, with its bend right at the Mauna Loa summit crater. Both Mauna Loa and Kilauea craters are on true fissure-eruptions lines, and each has built a bent ridge of outflow heaping, with summits at the bends.

The "pit", "the rim", the depth or depression to the "lava lake" or "floor of pit", the "lava column" or "relative rising" always refers to Halemaumau, measured from surveying stations on or near its upper margin. The entire history of endeavor at the Observatory has centered about Halemaumau. Major Dutton's "unknown factor" (1884) in volcanism refers to the heat source of Halemaumau. Dana, through a half century of profound cogitation, puzzled over the "ascensive force" and "eruptive" lowerings without visible outflow of Halemaumau.

The Observatory building near Volcano House (hotel) was a place for records, collections, seismographs, dark room, drafting, and publication, as well as telephone contact with the other volcanoes (chiefly Mauna Loa), and a base for expeditions (Pl. 1). It is more than 6 miles from Halemaumau with its hut equipped for camping and sleeping at the pit. On horseback one could reach the pit more directly (3 miles) by trail across the Kilauea fill. For many weeks in 1912 daily surveys were made with plane table of the changing height and inner topography of the lava lake.

The 1912 plat of changing elevation of lava column through a range of 300 feet, fluctuating about solstice and equinox, became a text for discussion and experiment; and the problem widened out to daily tide, 3-weekly flux, nature of gases, correlation of earthquakes and tremors, ground tilts, temperatures, causes of talus slides, opening of rim cracks, pit circularity, and shallowness of the liquid pools. Rate of movement up or down fluctuated widely, and extraordinary rise of border benches, without agreement with liquid lava, started speculation and experiment.

Most of these problems developed during 1912. Most of the lava pools were about 300 feet down and small. The sides of the pit smoked from fiery vents at several levels. Photography with panchromatic glass plates showed promise. An instrument shelter with rigid table, overhanging the north rim, was built for work at night, when vertical angular measurement was done during smoky seasons. The mapping of the hardened floors and talus glow holes was not successful in 1912–1913 owing to excessive smoke, and its importance was not appreciated until 1915, when it became evident that these hard floors were going up and down and were integral with the lava column.

Such are the interests, physical and chemical, in deciphering the meaning of basaltic magma at one of the few places on earth where it may be seen continuously. The seismograph records and other symptoms, accumulated for many years, make the quiet times even more interesting than "eruptions", though less exciting and less spectacular. For these precious records contain discovery yet incomplete, of prognosis *before* coming events. Such forecast is at the heart of successful science.

OBSERVATORY PUBLICATIONS

The Bulletin of the Hawaiian Volcano Observatory began with weekly reports to newspapers by Perret in July 1911, continued by Jaggar 1912–1913, and reprinted weekly as leaflets after June 26, 1913. They were not numbered but merely reprinted from the Pacific Commercial Advertiser, now the Honolulu Advertiser (1938).[1] The quarterly Report, January–March 1912, was replaced by the weekly and monthly Bulletin.

Prompt issuance was favored by weekly publication, in contrast to the delayed "annuals" of the Vesuvian Observatory. At times of volcanic crisis, promptness is important for observers and for readers, and a weekly press report has been mimeographed and sent to newspapers. The local resident population, school teachers, subscribers to volcano research, geologists at a distance, universities, research laboratories, observatories, and libraries receive the reports. This diversity has made the editing difficult, in steering between popular and technical interests.

Vaguely these things were foreseen when the Hawaiian Volcano Observatory was founded. Description of the foundation and of the preliminary work from 1909 to April 3, 1912, was printed in the first ***Report of the Hawaiian Volcano Observatory January–March 1912***, published by the Society of Arts of Massachusetts Institute of Technology, Boston. It was intended to continue routine reporting in this form, but Boston proved to be too far away, and, as the publication in Honolulu was required to stimulate interest in the Hawaiian Volcano Research Association, the monthly Bulletin came into existence. A second Report was published by the Massachusetts Institute by Harry O. Wood (1917b). The Reports have been Special Reports (Wentworth, 1938) since that time, the numerous volcanic activities of the Hawaiian volcanoes making it necessary to concentrate about the Bulletin and the Volcano Letter, with occasional papers in scientific journals such as the Bulletin of the Seismological Society of America, the Journal of Geology, and the American Journal of Science.

RECORD BOOK

The material in the Record Book of the Hawaiian Volcano Observatory from the second week of April 1912 to the last week of June 1913 was never printed except as newspaper reports in Honolulu. Hence it is reproduced here.

The routine of the Observatory had been determined by the necessity for continuous measurement with surveying instruments of the lava pool in Halemaumau pit. This was the principal thing that was changing, with the exception of local earthquakes, for which seismographs were being provided. From April until June

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[1] They were numbered Volume II, No. 1, weekly beginning January 7, 1914. They became monthly numbers August 1914, and with Volume III, No. 1, January 1915 (following No. 32), the monthly issues became systematic with numbering to 12 for each year, but divided within each issue into weeks. The title remained Weekly Bulletin until Vol. VII, No. 2, February 1919, when under U. S. Weather Bureau the title was changed to Monthly Bulletin. The change from weekly division to a journal for the entire month began January 1921. The Bulletin was replaced by an enlarged Volcano Letter in weekly issues beginning January 1, 1930. This publication was reduced for economy to a monthly in May 1932 and to a quarterly in December 1938.

1912, Frank B. Dodge, assistant in topography, recorded nearly every day the outline of the lava pool and its depression below the rim of the pit. Examples of this work appear in Figures 26 and 29 of the Massachusetts Institute Report of January-March 1912.

Seismographs were mounted in July 1912 by H. O. Wood who had come from the University of California to be seismologist at the Observatory. The instruments first set up in the seismograph chamber on the NE edge of Kilauea Crater were a large Omori major tromometer for recording E-W motion, a minor Omori seismograph, and an Omori ordinary seismograph, for recording strong motion; a two-component Bosch-Omori large tromometer of German manufacture awaited installation in 1913. The first two instruments were made in Tokyo. In the seismometric laboratory much of 1912 was devoted to instrumental adjustments. Regular reports on local earthquakes were added to the weekly report after September, and these gradually became systematic.

It became evident during this first year of systematic record that the two outstanding groups of measured data, centering around Halemaumau pit, for platting of curves were the topographic lava lake changes and risings and the data of earthquakes.

F. A. Perret (1908) had for years been reporting volcano fluctuations in Italy, affected by combinations of lunar and solar tidal stress. The year 1912 at Kilauea, with its long periods of daily surveys, revealed striking depression of lava with approach to equinox and rise of lava with approach to solstice (Jaggar, 1920, p. 178).

Earthquake frequency and intensity (Jaggar, 1920, p. 259, 173) also showed close correspondence with rise and fall of lava for both Mauna Loa and Kilauea. The diagrams there referred to (Jaggar, 1920, Pls. 15, 17, 24), for the first 5 years of the Observatory's work, demonstrated relationship between earthquake statistics and lava statistics, and for both of these a systematic relationship between Mauna Loa and Kilauea.

The journal here that covers the weekly activities of Kilauea Crater, as observed by the new observatory from April 1912 until June 1913, follows the form of the first Report (Hawaiian Volcano Observatory, 1912) and is a narrative from the last date in that report to the beginning of the published Bulletin of the Hawaiian Volcano Observatory. It was the object of all publications to preserve a connected narrative of the Hawaiian volcanoes from 1909 on; before that it was recorded in the books of Brigham (1909), Hitchcock (1911), and Dana (1891).[2]

Rising Lava of Halemaumau after April 4, 1912:

The period January-March reviewed in first Report of the Hawaiian Volcano Observatory included a rapid rise of the pit lava to a sea of melt, with many lines of traveling fountains of effervescence, between mid-October and January 1912. January 4, 1912, the surface of the Halemaumau lava was about 3635 feet above sea level, or 65 feet below rim. The column then lowered for a month to 331 feet below rim and recovered to depression level 264 feet on April 3. The datum station on the eastern verge was at 3700 feet.

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[2] It will be useful to insert in offset paragraphs comments of the present day (1938) critical of the attitude of the observers of 1912-1913, and explanatory in the light of later discovery. It should be remembered that the first gas collections of Day and Shepherd (1913) were made in 1912 and that critical reviews of this first decade of work were published by Perret (1913b), Jaggar (1917d, 1920), and Wood (1916) and in the Bulletin (Hawn. Volc. Obsy. III, No. 4, No. 5; IV, No. 4; V, No. 8; VI, No. 1).

Subsidence after a New Year high level had occurred in 1910 and was discovered in 1924 to be a habit of the declining years of an 11-year cycle (Pl. 74). The cycle now was 1902–1913 and approaching its end. The year 1913 after May was destined to be a repose period, just as 1902 had been. The curve of 1912 risings (Wood, 1917b; Jaggar, 1920, Pl. 17) proved to be seasonally systematic with equinoxial low levels and solstitial highs, leading at once to an interest in the lava tide as related to seasons.

The rise April to July received a severe reversal of more than 100 feet from May 23 to June 20. After the lowering, and just at solstice, the lava turned, to boil up 150 feet in 18 days with unprecedented heat and gas action.

KILAUEA FROM APRIL 6, 1912, TO JUNE 17, 1913

WEEK ENDING APRIL 11, 1912

The lava lake of Halemaumau rose slowly, as it has for the past 3 or 4 weeks, and is now within 248 feet of the top.

The average for the week was 252 feet below the N rest house. The following are the daily levels:

	Feet
April 6, 8:30 p.m.	259
8, 11 a.m.	257 (Fig. 1)
9, 10:30 a.m.	249
10, 5 p.m.	249
11, 9:30 a.m.	248

April 8 the smoke, which had been so bad at different points surrounding the lake, lessened, and there was a much better view of the lake from the north side, which until then had been entirely shut off. This decrease of smoke is one reason the lava was thought to be steadily rising. The current was strong from the east. Cones had been built up on the NE bank and at the S, but they were inactive at 11 a.m. when the survey was made. A new cone at the E end of the lake glowed red, and the lake was very active in the S cove (Fig. 1).

April 9, at 10:30 a.m., the lake overflowed on all sides. Large cones had been built up at the NW corner and W end, spouting lava at intervals. The streaming was strong and to the east. The lake appeared about a foot below its banks.

April 10, the lake was about the same with a strong easterly set to the streaming. The small cone at the pinnacle was very active, throwing up lava 30 or 40 feet. The pinnacle here referred to had been a conspicuous object in the SE corner of the pit since February.

April 11, at 9:30 a.m. there were no overflows, although the lava was higher and more active due to the building of the walls.

The little cone at the pinnacle was emitting vapor with considerable hissing with now and then a shower of lava. There was a high cone at the W end open at the top, and another at the NW corner of the lake.

F. B. D.

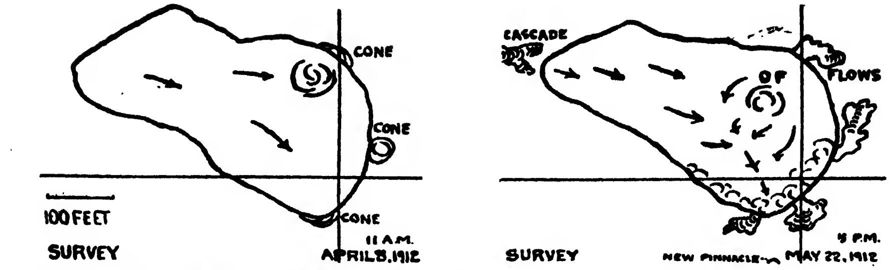
WEEK ENDING APRIL 20, 1912

The lava in the crater of Kilauea is still rising, reaching its greatest height of 227 feet below the rim April 20. The average depression for the week was 239 feet. The following are the daily levels:

	Feet
April 13, 10 a.m.	241
14, 8:30 a.m.	244
15, 11 a.m.	242
16, 9:45 a.m.	247
18, 5:30 p.m.	239
19, 5 p.m.	234
20, 10:40 a.m.	227

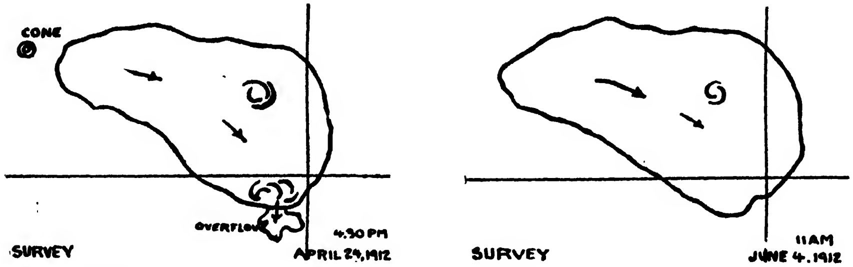
The measurements of depth at this time were usually referred to the N station.

There were a number of very large overflows during the night of April 12. These were flowing at 10 p.m. and extended beyond and higher than anything previous and brought the floor of the pit to within 20 feet of the top of the pinnacle, which 2 months ago stood 60 feet or more above the lake.



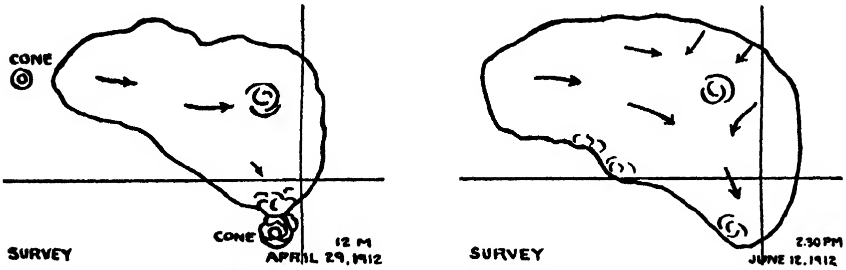
a. April 8; eastward streaming. Cones and fountains east.

e. May 22; intense overflow.



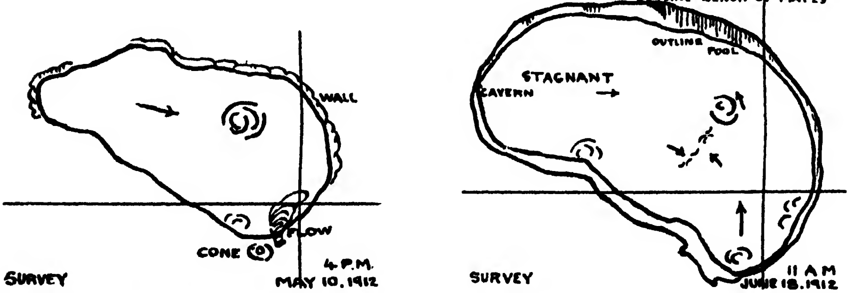
b. April 24; same with southern overflow of bank.

f. June 4; quiet.



c. April 29; recovery of south cone.

g. June 12; southern fountains enlarged lake.



d. May 10; inward flow and lowered lake.

h. June 18; lowered lake. Streaming reversed.

FIGURE 1.—*Lava lake maps April–June 1912*

Maps of liquid lava lake in bottom of Halemaumau Pit, Kilauea Crater to scale shown. Co-ordinates 155° 17′ 8″ W. Long., 19° 24′ 33″ N. Lat. Consecutive with sketch maps of Report Hawaiian Volcano Observatory January–March 1912. Arrows show streaming, pattern indicates fountains, OF means "Old Faithful". Depression below rim of pit may be found in Part 1.

April 13, at 10 a.m., the lake was very active, with an easterly surface current. There was a peculiar looking cone on the north side, open on the top and roaring continuously. The lake was brimming to the highest part of its banks.

April 14, at 8:30 a.m., no important change had occurred, but a high rampart had been built at the W end. The current was still toward the E, and the blowing cone at the NE corner continued to roar.

April 15, at 11 a.m., the lake was very active along the walls of south cove, with the rest quiet. There were five or six overflows the following night. The current was slow, eastward.

April 16, at 9:45 a.m., the current was more rapid and to the east, the greatest activity was on the south side near the wall, and there were cones at the W end, NW corner, and the S cove. Judging from the banks the lake appeared low. A loud hissing sound was heard from the NW cone.

April 18, at 5:30 p.m., many new overflows were seen, the current was eastward, and the pool was brim-full. It had risen 8 feet and was more active than at any previous time during the week.

April 19, at 5 p.m., the lake was very quiet with westerly flow.

April 20, at 10:40 a.m., there was a strong easterly flow, rising in the extreme west end and sinking in the east. The lake was very active especially in the south cove, and three overflows were observed within 15 minutes.

F. B. D.

WEEK ENDING APRIL 25, 1912

The lake of lava is somewhat smaller than when Professor Jaggar started the scientific work here in January, but nevertheless it is just as interesting inasmuch as it has risen about 65 feet.

The depth below the rim now is 220 feet. The lake measures 434 feet by 244 feet. The following are the daily levels:

	Feet
April 21, 10:15 a.m.	236
22, 10 a.m.	229
23, 4:25 p.m.	227
24, 4:30 p.m.	223 (Fig. 1)
25, 9:20 a.m.	220

The average for the week was 227 feet. These measurements of depth are from vertical angles from the N station to the S cove of the pool.

April 21, at 10:15 a.m., the lake was about 9 feet lower, showed numerous overflows and a swift current. During the day it subsided, and the current became more sluggish.

April 22, at 10 a.m., new overflows were seen on the floor, and the lake was brimming so that four distinct flows streamed over the platform at one time. The current was eastward, and fumes were rising from the cones W and NW.

April 23, at 4:25 p.m., the lake was very active, and a large overflow occurred at the S cove. Current was eastward as usual. The pinnacle SE, which at the beginning of the year stood 60 feet above the lake and has been a prominent landmark throughout the Spring, is now submerged. Its position is marked by a blowing cone, where lava spray and flame are playing.

April 24, at 4:30 p.m., an immense cone about 40 feet back of the W end spouted lava and flame into the air, at the same time roaring loudly. The average interval of Old Faithful was 50 seconds. There were many large overflows through the day and a strong easterly current. Three flows were running at the time of observation.

April 25, 9:20 a.m., the lake was practically the same but 3 feet higher, and the current eastward as usual.

F. B. D.

Method of Survey:

These reports are by Frank B. Dodge, who was later with C. H. Birdseye in his boat trip through the Grand Canyon. The method was to ride daily over the trail from Volcano House to Halemaumau and occupy with plane table and alidade at least two triangulation stations marked on the pit rim. Thus were obtained graphically the horizontal distances to points in the outline of the lava lake. The United States Geological Survey bench marks had been located by Birdseye and Burkland (1912) in February and gave a base line for locating the rim stations. Given a horizontal distance to marginal splashing grotto of lake, it was simple trigonometry to determine its depression. A special right-angle triangle board, with protractor reading to minutes, was built for this work. The scale was 100 feet to the inch, and this scale was retained for platting pit maps for many years, using rulers divided into hundredths of an inch. Owing to smokiness of the pit in 1912–1915, there were many days when nothing could be seen clearly. Eddies of the wind made certain parts of the rim better places for observations. Photographs helped the surveys, and range-finding experiments were tried (Pl. 3).

Old Faithful was a lava fountain spot in the lake in the northeastern region that burst into ebullition rhythmically about every 45 seconds. A second rhythmic fountain—New Faithful—developed in the western pool later. "Activity" refers to convectional surface streaming in the liquid effervescing slag, temporary lowering with break-up of crusts, pounding in-suck with fountains at border stalactite grottoes under the black glassy spatter banks, and all the fiery gas action that fluctuates.

WEEK ENDING MAY 2, 1912

The lava lake has fallen 13 feet in the last 3 days; otherwise it is as it was last week. The following are the daily levels:

	Feet
April 26, 3:30 p.m.	220
27, 4:45 p.m.	217
28, 2 p.m.	214
29, 12:25 p.m.	216 (Fig. 1)
May 1, 4:30 p.m.	225
2, 10 a.m.	227

The average for the week was 220 feet below the rim. The vertical angles were measured from the N station to easterly points on the shore of the lake, mostly S cove.

April 26, 3 p.m., the lake was active around the S cove, and a tunnel was formed through the bank, coming out about 15 feet back and throwing lava on the old flows. The night before there was a large overflow at the E end.

April 27, 4:45 p.m., easterly current very active. The activity shifted regularly from one side to the other and seemed to encircle the lake along its edges. The activity was greatest in the S cove.

April 28, 2 p.m., easterly current into Old Faithful mostly. Old Faithful very active.

April 29, 12 noon, lake most active at S cove, with the hole through the bank throwing lava half way across the old flows. Cone at W end spouting lava. Easterly current. The lake measured 430 feet long by 240 feet wide, 216 feet down from E station.

May 1, 4:30 p.m., the lake had sunk considerably. There was a very slow eastward current, with explosions of Old Faithful at short intervals, outdoing itself in the height to which the lava spouted. The lake appeared about 7 feet below its banks. Cone at S cove had large summit cavity, glowing within.

May 2, the lava was 2 feet lower, the current eastward and still very sluggish. Otherwise as on the day previous.

F. B. D.

WEEK ENDING MAY 9, 1912

There has been very little change in the crater during the past week. The lake is slowly rising, recovering from its drop of 13 feet on May 1.

The following are the daily levels:

	Feet
May 3, 4 p.m.	228
4, noon	226
5, 4:30 p.m.	222
6, 1:15 p.m.	216
7, 10:30 a.m.	216
8, 5:15 p.m.	211
9, 10 a.m.	218

The average for the week was 219 feet vertically below the rim. The measurements were to the S cove from N station, except May 7, which was to S cove from E station.

On May 3, at 4 p.m., the lake was exceptionally low if judged by high walls surrounding it. Old Faithful was very large and active, and there was a slow easterly current.

The surface currents seem to slacken if the lava sinks and become very swift if it rises. Old Faithful has shorter intervals and is larger as the lava recedes.

May 4, at noon, the lake had risen 2 feet.

May 5, at 4:30 p.m., the lava was 4 feet higher with a strong easterly current. There were three or four overflows the previous night. A cone north of the lake had become active, throwing lava high into the air.

May 6, at 1:15 p.m., the lake was 6 feet higher and overflowing. There was a rapid eastward current pouring into the vortex of Old Faithful. The whole floor of the pit was covered with new flows of the previous night. Loud hissing as though from steam valves seemed to come from the cones at the S cove and W end of the pool.

On May 7, at 10:30 a.m., the lake was still overflowing, there was easterly current, and a small new overflow appeared on the platform. Old Faithful was fountaining in large domes at short intervals. The cone SE, where formerly the "pinnacle" had been, was spouting lava 60 to 70 feet and forming flows all around it.

On May 8, 5 p.m., the lava had risen 5 feet but had built high splash walls around it, making it look as if it had sunk. The cone at the S end was spitting lava and overflowing and had a long blue flame at the top. Strong easterly current.

On May 9, at 10 a.m., the lava had subsided 7 feet, and the easterly current became sluggish but with Old Faithful active.

Half way up the wall at S cove an opening had formed connected with the lava passage that had built up the cone, and instead of the lava shooting from the cone, it would be forced out of this lower hole and spread over the east end of the lake. There was a marked increase in smoke.

F. B. D.

WEEK ENDING MAY 16, 1912

This week the volcano was quiet. A slight rise and then a little larger fall was noted.

	Feet
May 10, 3:45 p.m.	220 (Fig. 1)
11, 11:15 a.m.	218
12, 3:15 p.m.	211
13, 3:30 p.m.	215
14, 5 p.m.	213
15, 3 p.m.	222
16, 9 a.m.	222

The average of 217 feet is 2 feet higher than last week. The measurements were made from the N station, using the S cove as location point.

May 10, at 3:45 p.m., the lake was lower with easterly current. The record of survey this day is shown in Figure 1.

May 11, at 11:15 a.m., the whole lake was inactive, the eastward current was slow, and the fumes had increased.

May 12, at 3 p.m., the lava rose about 7 feet and overflowed, with a strong easterly current. One overflow covered the whole S side of the pit, while numerous others covered the N side. The pit was nearly free from smoke. At the bottom of the cliffs the edges of the new flows glowed red in a continuous circle.

May 13, at 3:30 p.m., the lava had sunk about 4 feet with its whole surface frozen, making it nearly impossible to see any of the red-hot lava except when Old Faithful occasionally boiled up sluggishly. The current was rising through the middle in a line from end to end and flowing toward the north and south sides, which is very unusual.

At 8 p.m. the lake was at the same elevation but quite active and with the easterly current restored. The cone at the S cove had an opening in its side and kept shooting out sparks about 50 feet, at an angle of 45°, and blue flames, like a huge Roman candle.

May 14, at 5 p.m., the lake showed no important change, the lava was quiet, and the current was sluggish and to the E.

May 15, at 3 p.m., there was easterly current, and measurement indicated a sinking of 9 feet.

May 16, at 9 a.m., the depression was the same, there were dense fumes, the current was eastward, and the greater activity was at the E end of the lake.

F. B. D.

"Champagne Cork" Effect:

This week's culmination of high level revealed a mechanism of lava rising within the pit walls, to flow from the walls, from a level above the lake, that is important. This was photographed by A. L. Day (1913, Pl. 26). Where the difference of level, defying hydrostatic principles, was here 19 feet, a difference of 300 feet at the wall of Halemaumau characterized such cascades in 1934. Such lava springs of differing height as incidents of a rapid rise of the Halemaumau lava column—certainly not individual siphon tubes from a higher reservoir—are products of gas foaming. This may be called the "champagne cork" effect.

WEEK ENDING MAY 23, 1912

On May 23, the lava lake reached the 200-foot depression mark and for the last 3 days has been unusually active. This is the highest level of the spring season to date, culminating in an earthquake and a lava cascade from the wall.

The following are the daily levels, measured from N station to S cove:

	Feet
May 17, 11 a.m.	225
18, 5 p.m.	227
19, 12:10 p.m.	214
20, 12:30 p.m.	218
21, 11 a.m.	215
22, 4:45 p.m.	205 (Fig. 1)
23, 9:40 a.m.	200

The average of 215 feet is 2 feet higher than last week. The dimensions of the lake by survey May 22 were 465 feet by 263 feet.

May 17, at 11 a.m., the lava was very inactive, with a slow easterly current and Old Faithful splashing on the bank at the E end. There was much smoke.

May 18, at 5 p.m., the current had become very strong; otherwise there was no change. The pit was very smoky.

May 19, at noon, the lava had risen 13 feet but did not overflow. There was a swift current and little smoke. This was to lead to one of the remarkable culminations of the year 4 days later. During the night of May 19 three small overflows took place.

May 20, at noon, the lava had sunk 4 feet. Strong easterly current and less smoke.

May 21, at 11 a.m., the lake had risen 3 feet. There was strong easterly current and practically no fumes. It was very active around the S cove. The big cone 150 feet to the south of the S cove had become active and built itself up about 20 feet, throwing out lava and covering the floor surrounding it with flows.

May 22, at 7 a.m., there was an overflow with the whole lake very active. At 4:30 p.m., there was great activity. The lava continuously overflowed with an easterly current estimated at about 5 miles an hour. A whirlwind in the W end on top of the bank formed a column of smoke 5 or 6 feet in diameter and rising 200 feet in the air and lasting 6 or 7 seconds. The night before the new pinnacle cone S of the pit poured out a steady stream of lava about 2 feet in diameter, rising about 20 feet and filling up the S basin; the surface current of the lake flowed in a circle, rising in the W end and not seeming to sink or be sucked down anywhere. At 5:30 p.m., the currents changed, rising at Old Faithful and at the W end, meeting in the middle of the lake and flowing into the S cove.

May 23, at 9:30 a.m., the lake was still higher and overflowed continuously, with swift easterly currents. A huge cone was built at the W end during the previous night. At a point 200 feet west and 20 feet above the floor, during the morning, lava broke through the walls of the pit, forming five cascades falling about 19 feet and flowing about 30 feet horizontally on the outer rim of the platform, which is there somewhat lower than at the edge of the pool. The platform was a dome with the lake at its top. The cascades first started with a puff of smoke and a little muffled explosion followed in a few seconds by other explosions which finally blew off the outer layer of the cliff's surface, allowing the lava to pour out. The measured depth from N station to the vent in wall where cascades emerged was 181 feet, while the depth to the lake surface at the S cove was 200 feet. An earthquake was felt here and elsewhere in Hawaii.

F. B. D.

Collection of Lava Gases:

This week was characterized by the beginning of a pronounced lowering of the lava, so that the party led by Day and Shepherd (1913, p. 581) from the Geophysical Laboratory took advantage of the high level to make the important collection of volcanic gases, by pumping, that was to set a standard for many years to come concerning field methods in chemistry of volcanism. The work so begun with a suction pump, and a train of pipe thrust into an active lava spatter-cone, was carried forward by Shepherd (1938) and Jaggar (1940) later using vacuum tubes and recently by Ballard and Payne (Ballard, 1938) using suction pump. This was the beginning of one of the most important activities of the Hawaiian Volcano Observatory, whereby gas is conceived to be the most fundamental agent in the rising, expanding, and heating mechanisms of magma, in its escape at volcanoes and in its contact effects at intrusions (Sapper, 1927, p. 32).

WEEK ENDING MAY 30, 1912

The lava lake has relapsed into subsidence. The following are the daily levels below the N station, mostly measured on the shore line at S cove:

	Feet
May 24, 4:15 p.m.	208
25, 3:30 p.m.	217
26, 4:45 p.m.	214
27, 2:40 p.m.	216
28, noon	219
29, 11 a.m.	218
30, 9:30 a.m.	222

The average depression for the week was 216 feet.

May 24, at 4 p.m., the lava had fallen 8 feet and was very inactive except for a little boiling in the E end. The overflow from the lava cascade in the side of the cliff had flowed around the outer edge of the floor of the pit, nearly connecting on the E side. The lava was still flowing under the hardened crust, breaking out occasionally. The large SE cone and the cone at the W end showed internal glow. There was slow easterly current.

May 25, at 3 p.m., the lake had fallen, with a very slow easterly current. It was very active at the S cove where it appeared to be sucked downward. The banks about the lake were high. The encircling flow from the western cascade now formed a ring around the platform, the two semicircular flows meeting under the E station. The lava of the cascade was still flowing under the crust, now and again breaking out at new places. The pinnacle SE and the W cone were glowing, and there was much smoke.

May 26, at 5 p.m., the walls about the lake were high, and the eastward current was stronger. The cascade lavas were still flowing under a crust. The fumes were dense, and the cones glowed. In the night liquid lava broke through cracks in the region of the cascades W.

May 27, at 3 p.m., the lake showed steady subsidence; the current was slow from the E and W ends, meeting where the surface skins were sucked under. Old Faithful was large and bombarded the bank of its cove. There was an unusual quantity of fume. Red glow was still seen at the cascade, at the new pinnacle cone SE, and at the W cone.

May 28, at noon, subsidence continued, there was rapid easterly surface flow, the depth from N station to S cove was 219 feet, and the cascade was still overflowing. Both cones glowed red, and there was fuming.

Messrs. Day, Shepherd, Dodge, and Alec Lancaster descended to the floor from the E end of 1894 bench, with the aid of a rope, and collected gases from the flame vent of SE cone.

May 29, at 11 a.m., the lake was inactive, with moderate easterly current and dense fumes.

May 30, at 9:30 a.m., there were walls around the lake, which was subsiding. The current was eastward and moderate. Activity was strongest at the E end. The SE new pinnacle cone appeared to be extinct. Fumes were dense.

F. B. D.

Week Ending June 6, 1912

The lava lake of Halemaumau has lowered more than 40 feet since last week and remains at a low level and very inactive. The lava levels below the E station were:

	Feet	
May 31	about 230	
June 1	about 235	
2	about 245	
3	about 235	
4, 11 a.m.	230	(Fig. 1)
5, 3:30 p.m.	240	
6, 9 a.m.	242	

The lake is surrounded by 40-foot walls, from which occasionally sections break off and fall into the lake creating great effervescence in the lava. Some of the pieces are over 150 feet long and from 15 to 30 feet thick. The pit is filled with dense clouds of gases which obscure the lava. The two cones and the lava cascade, so active a few days ago, have died out.

June 4, 11 a.m., the lake was low and inactive, with slow easterly current. Old Faithful explosions were small. There was much fuming. Talus debris appeared at the foot of the inner wall, and avalanches took place occasionally.

June 5, at 3:30 p.m., the lake was 10 feet lower with slow easterly current. Huge pieces of the wall on the S had fallen in. Old Faithful fountainings were small, and there was much fuming.

June 6, at 9 a.m., the lake appeared low with easterly current. There was a great pounding and fountaining along the S side; much smoke.

F. B. D.

Return of Jaggar with H. O. Wood:

On June 13 the Director of the Station, Dr. T. A. Jaggar, returned from California, and these reports are by him from June 20 onward. He was accompanied by H. O. Wood, with whom he had been associated at Harvard University and who had as geologist become trained in seismology as a result of association with Lawson (1908), Gilbert, and others in preparing the monograph of the San Francisco earthquake of 1906 for the Carnegie Institution of Washington. Mr. Wood had been operating Omori seismographs at Berkeley. He was appointed Associate in Seismology at the Observatory and during the next 5 years he prepared the reports on the results of using seismographs in a cellar on the northeast edge of Kilauea crater, and later at the edge of Halemaumau the inner pit.

Week Ending June 13, 1912

The lava levels have been lowering for the past week, and the total drop since May 23 has been 70 feet.

The following are the daily levels, below the N station to S cove:

	Feet	
June 7, 11 a.m.	246	
8, 9:45 a.m.	249	
10, 8 p.m.	260	
11, 5 p.m.	265	
12, 2:30 p.m.	263	(Fig. 1)
13, 11:45 a.m.	270	

The average for the week was 259 feet.

With the sinking of the lake, the high walls surrounding it have been falling in, enlarging it and changing its shape so that it now measures 515 feet long by 320 feet wide (survey of June 12). The whole floor of the pit has sunk about 8 feet, forming ridges and wall ravines over its surface, and in some places the disturbances are very marked as at the pinnacle cone, where the lava is piled up in a mass of broken rock. Surrounding this cone seems to be a very weak spot as the floor has sunk more than at other places.

June 7, at 11 a.m., the current was stronger than it had been for a long time, and the lake was active along the S wall. There was increase in fumes.

June 8, 10 a.m., the easterly current had become slower, and the pool was inactive.

June 10, at 8 p.m., SE cone began to awaken, throwing a few sparks out and glowing brilliantly from two large openings. The slow easterly current from the W end was opposed by a faster one from Old Faithful cove NE. They met near the S wall and sank, and there the surface skins were engulfed.

June 11, at 5 p.m., the lake was active in the east end, the S cove, and Old Faithful. Most of the walls fell in leaving a greatly changed outline. The main tumble was about the S cove. There was slow easterly current, and the pool was 265 feet below the N station.

June 12, 2:30 p.m., the lava was very quiet except for a short distance along the S bank. The current was rising out of Old Faithful and the W end, meeting in the middle region, running into the S cove. The floor of the pit appeared sunken 7 or 8 feet. The fumes were denser. (*Compare* shape with May 22, Figure 1.)

June 13, at noon, lava nearly still; just the slightest eastward movement could be detected on the surface, and the high walls were beginning to crack again. There was an active region along the wall of the S cove, and W of Old Faithful the lava was sinking a little. The floor of the platform W of the SE pinnacle cone had subsided considerably.

F. B. D.

WEEK ENDING JUNE 20, 1912

The following are the lava levels of the pool during the past week:

	Feet
June 14, 5:20 p.m., below N station	278
15, 9:45 a.m., below N station	285
16, not recorded	
17, 11:30 a.m., below N station	300
18, 11 a.m., below N station	313 (Fig. 1)
19, 2:45 p.m., below E station	318
20, 8:40 a.m., below E station	322

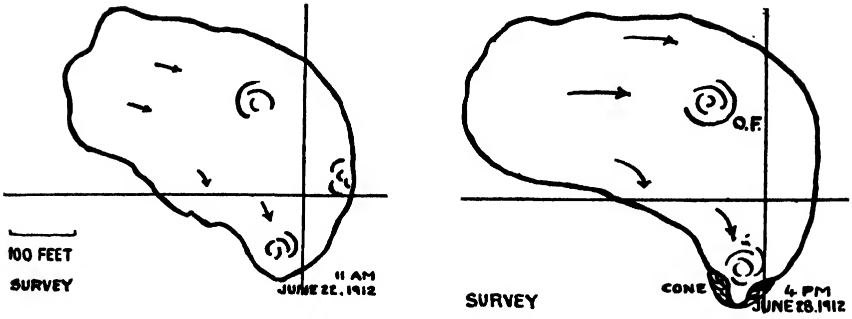
The measures were to the SE cove or the promontory next west of it. The average depression for the week was 303 feet.

The stations referred to are trigonometric ones, marked by small concrete triangular platforms. The average depth of the lava surface below the rim for the week was 302 feet. The general movement of the column has been a sinking, fairly uniform for the past 2 weeks, the minimum being a slight rise of 2 feet on June 12, the maximum a fall of 13 feet on June 18. The average fall per day has been 6 feet 1 inch during the past 13 days. The present level of the lava is the lowest since January.

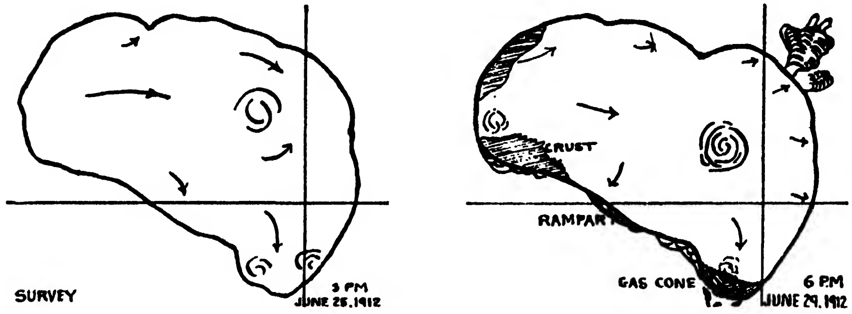
With the subsidence there has been pronounced slumping of what was the 200-foot floor or bench surrounding the high lake of May 23. This bench during June has been a broad flat terrace surrounding a precipitous wall which bounded the lava pool. As the pool sank it left spatter rims at successively lower levels on this cliff face. These are best preserved about the W end of the pit, but the easterly portion has caved in, obliterating them, and lately spectacular caving has been frequent at many points.

The pool has enlarged since May 23 because of the falling away of the rampart, formed at the time and of the walls since.

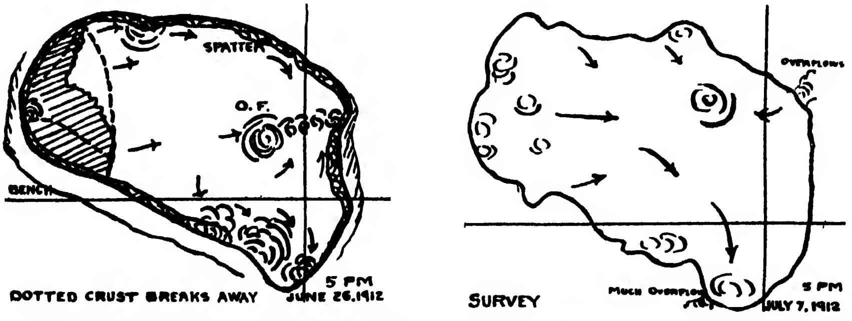
The writer returned to the station June 13, accompanied by H. O. Wood who is engaged in setting



a. June 22; normal. d. June 28; inflow at south cone.



b. June 25; enlarging lake. e. June 29; rampart building and overflow.



c. June 26; bench border activity, skin over western source. f. July 7; increased rising and development of coves

FIGURE 2.—*Lava lake maps June–July 1912*

(*See* Figure 1.)

up the seismographs. On June 16 a reconnaissance of the NE flank of Mauna Loa was made, across the flow of 1852 and as far as the flow of 1881. There is no sign of activity on Mauna Loa.

June 14, 5 p.m., the fumes were heavy from the western vent, where lava cascades were emitted May 23, and also from the E, near the debris of SE pinnacle cone. The surface currents arose along the S wall and flowed N, but the W end of the pool was nearly stationary.

June 15, 10 a.m., the current flowed slowly eastward, the lake was very quiet, and the Old Faithful fountain small.

June 17, 11:30 a.m., the lake was quiet and nearly frozen over; there was a very slow eastward current which bent its course into the S cove. The terrace floor showed signs of cracking and subsidence, especially W and S of the eastern fuming cracks, which had increased in extent, and N of the lake the bench had slipped down 20 to 30 feet. Fumes had increased. The surface of the lake had reached 300 feet depression.

June 18, 11 a.m., the lake showed currents from both W and E meeting in a NNE-SSW line of downfolding surface blankets; there was some bombardment of the NE shore. In the morning many tons of rock fell from the terrace at the E end and were engulfed in the molten lava and instantly foundering, and a reddish-brown bulbous cloud of dust and fumes rose from the tumble. A great wave was started in the lava which propagated itself across to the W shore. Violent ebulition always occurs in the molten fluid where these avalanches sink. Great sluggishness characterized the surface currents, and the fumes from border vents about the terrace level or higher have been increasingly dense. Heavy lava stalactites were hanging in caverns over the pool W and N. The period of Old Faithful varied from 35 seconds to 1 minute.

The lake was 530 feet long by 290 feet wide, with a broad cove extending the pool to the SE. The edge of the lava pit at the terrace level measured 550 feet long by 335 feet wide (Fig. 1). Fumaroles were located in the pit as follows:

Position	*Depression*	
170 feet SSE of S cove	219 feet below N station	
125 " S " " "	233 " " " "	
30 " SSW " " "	242 " " " "	(New Pinnacle)
300 " SSS " W end	179 " " " "	
150 " W " " "	188 " " " "	(Cascade)
200 " N " pool	217 " " E "	(N cracks)

The edge of the terrace of platform of May 23 was now at the west end, 65 feet above the lake; at the south cove, 66 feet; and at the east end, 74 feet (Fig. 1).

Blue and whitish fumes filled the pit almost incessantly. These came from many places; there are three eastern vents as shown in the above table, at levels 219, 233, and 242 feet below the rim, respectively, the last being the ruin of New Pinnacle cone. There is a fuming patch SW of the inner pit, 179 feet below the rim, consisting of a rough jumble of sulphur-coated boulders and crevasses. On the W the lava-cascade vent 188 feet below the rim has been fuming for many months. And lastly there is a deep crack with increasing fumes under the N wall of Halemaumau, 217 feet below the E station. The bench has both slipped down along this crack and slumped slopingly away from it toward the sinking pool.

June 19, at 3 p.m., increased activity occurred about the east-central and southeastern parts of the pool, but the W end was quiet, the bench continued to subside, and the fumes were dense. The current was slow eastward.

June 20, at 9 a.m., there was moderate activity and an easterly current; an unbroken piece of the wall at the W had slipped down and formed a bar across the lava cavern there, with fluid on both sides of it, that on the side of the pool surging against the bar.

T. A. J.

WEEK ENDING JUNE 27, 1912

During the past week the lava pool reached its low level at the time of the summer solstice and rose rapidly immediately thereafter.

The following were the lava levels of the week:

	Feet
June 21, 12:10 p.m.	328 feet below E station
22, 11:20 a.m.	329 feet below E station (Fig. 2)
24, 2:45 p m.	323 feet below E station
25, 3 p.m.	281 feet below E station (Fig. 2)
26, 5:30 p.m.	265 feet below N station (Fig. 2)
27, 2 p.m.	239 feet below N station

The average depth of the lava surface below the rim for the week has been 282 feet. The general sinking, which began late in May after the rise to the 200-foot level of May 23, continued to June 22, slacking during the 4 days preceding that date to an average of 4 feet per day, and rising from June 23 to 27 at an average rate of 18 feet per day, with an extraordinary leap of 42 feet in the 24 hours between June 24 and June 25.

With the change from falling to rising there was the usual diminution of visible vapor from the fuming patches around the walls of the pit, so that the lake is very clearly visible at times and presents a fine spectacle with streaming and active fountains. It is rising steadily and today overflowed; the bench, however, is below its original level, in consequence of recent slumping.

The weather of the week has been fair daytimes, with much cloudiness and misty rain during the nights and all day on June 27.

June 21, at noon, there was a very slow current eastward, much of the pool being nearly stationary. The walls had fallen in on the bar across the lava at the W end, obliterating the pool behind the bar as in a sand bar. This strip was the definite emergence of a bottom. There was no other change except that a portion of the wall had fallen at the northwestern bend of the inner cliff.

June 22, at 11 a.m., the current from the W was in motion, the lava on the E and S shores of the pool was in ebullition, and a tunnel in the direction of the fuming vents was much in evidence at the edge of the lake in the S cove, which appeared eaten away. The lake reached its low level for this season, 329 feet below the E station, and the SSE fumarole (*see* June 18) was now 228 feet below the N station instead of 219 feet as measured June 18, showing the effect of general slumping of debris carrying the fumaroles with it. Similar measurements made on points along the upper edge of the cliff over the lake gave:

Cliff at E end	234 feet below N station (June 18, 239 feet)
Cliff at W end	247 feet below N station (June 18, 248 feet)

These points are not identical with those chosen for location June 18, as the whole edge of the cliff of that time has fallen in, and the pool area is enlarged. The new edge of the cliff is higher than the cliff edge of June 18, because after subsidence the platform of overflow (of May 23) sloped inward, and the new points located were up that slope. The eating back of the cliff edge up the slope of the surface of the platform has evidently nearly kept pace with the general subsidence from June 18 to date, hence the level (below a fixed datum) of the upper edge of the cliff has changed but little. The materials of the SE fumarole, at a higher level, have subsided 9 feet.

June 24, 3 p.m., signs of rising were evident, the fumes were less dense, Old Faithful fountain was larger, no stalactites were visible under the banks, the W end wall was glowing some distance above the pool, and small fountains were numerous. Measurement indicated the lake had risen 6 feet, and the turning point was about June 23.

June 25, at 3 p.m., after the great 42-foot rise, the eastward current was strong, Old Faithful and another shifting fountain played frequently, and general activity on shores and in the pool was marked. Many small fountains were playing over the surface, making a peculiar "baby fountain pattern" which later became one of the marked features of the activity of this year. The fumes were greatly diminished. A survey on this date (Fig. 2) shows the lake to be as large as the cliff outline of May 23 and much larger than the lake of June 22. The depression below the E station was 281 feet. The upward leap of the lava column on this date was the beginning of a month of remarkable activity, characterized by the emission of vast quantities of gas, many fountains, high temperature, and great luminosity.

June 26, 5 p.m., the lava had risen 15 feet higher, but the lake appeared still to be 15 feet below the edge of the platform. There was strong easterly current, very little fuming, and shifting areas of fountaining. A spatter bench had formed around the lake, and the location of shore bombardment was continually changing. A crusted area of uprising at the W end became torn, and the crusts broke away and floated out into the pool every 15 to 20 minutes.

Fumes were rising back of the New Pinnacle (SE) and back of the platform N, there was diminished fuming from the high S sulphur patch and almost none from the cascade locality at the W end. Over the frozen cascade a black hole had formed. There was marked sulphur stain on the high walls W of the cascade.

The N fuming cracks at the outer border of the platform of May 23, under the 1894 bench, have opened and faulted down in two benches. The S platform of December 1911, which has been obscured by fumes, has slumped much, and the wall back of it is brilliant yellow, green, red, and gray.

June 27, 2 p.m., the bench was overflowed and overflowing, and a large three-sided cone was formed on the bank at the S cove, with active lava sputter in its center. The current was rapid and mostly eastward, and there was great turmoil in the S cove. The fumes had diminished, and the depression of lava surface was 249 feet.

T. A. J.

Seismographic Instruments:

Preceding foundation of this Observatory, instruments for the study of earthquakes had been purchased in Tokyo and from Bosch in Strasbourg, mostly horizontal pendulums designed to write earthquake records on clockwork-driven drums covered with smoked paper. These were similar to the instruments of Professor F. Omori of the Seismological Institute of Japan and were chiefly of his design. Later some of the instruments were remodeled by the physicists who worked at the Observatory, especially for dealing with strong and vertical motion, for tests of optical registration on bromide paper, and for the study of tilting of the ground (Pl. 4).

WEEK ENDING JULY 4, 1912

The lava lake rose steadily to July 1 and thereafter subsided 13 feet. The following are the daily levels, measured to the S cove, below the north triangulation station:

		Feet
June 28,	3:40 p.m.	241 (Fig. 2)
29,	4:20 p.m.	238 (Fig. 2)
30,	5:00 p.m.	234
July 1,	4:30 p m.	244
2,	12 noon	247

June 28, at 4 p.m., the lava was very active, over its whole surface, especially at the S cove where a huge, three-sided cone is being built up. There was a strong easterly current. While observations were being taken during only a few minutes, the lava rose 3 or 4 feet, overflowing and covering all the previous flows, the new flows running to the base of the cliffs.

June 29, at 4 p.m., the lake was still very active, having numerous small fountains playing over its surface with much larger ones active along the south wall. Old Faithful was occasionally violent making concentric waves. There was a strong southeasterly current. Very little smoke was visible. The cone at S cove had been roofed over with the lava spatterings of the night before. During the morning there had been new overflows, and a low rampart was growing, especially along the S shore.

At 5:25 p.m., an overflow from the NE corner of the pool showed the following characteristic mechanism: The lava attacked the bank with fountains and seemed to mount it in a series of surgings. It poured over a bank having no rampart and spread into a puddle. The surface skinned over, and the new stream made a way for itself through this skin. The skin wrinkled in folds parallel to the front of the advancing stream and was left in strands at the side of the stream, so that finally there were two longitudinal side curtains for each stream, and transverse festoons across the stream, which may be twisted into ropy forms by differential speed of flow between middle and sides of stream, and between upper surface and the more liquid lava beneath. Underlying red melt was seen through the fissures maintained open between the streams and their side curtains. When the festoons at the lower extremity of a flow stagnated, toes of glowing melt emerged from under the skirt of the flow, protruded a few feet in cylindrical masses as though from tubes under the festoons, and hardened. The festoons ceased to move and then were revived by overflow twice. The inner portion of the flow was liquid and incandescent, but this showed only on the margins and at the source. The newly erupted liquid almost instantly changed from lemon yellow, through orange, cherry red, purple, purple-gray, and silvery gray to brownish black with a gray sheen. All the overflows on the platform showed heavy drapery folds from overflooding in broad sheets. The maximum flooding had been on the N and S sides.

At 5:50 p.m., the "bee-hive" or gas cone at the S corner, which had an open cavern under which the lake surged, began to cave in. Back of it were three red-hot fuming vents on the side away from the lake.

This cavern had been quiet, but at 6:05 p.m. it was bombarded with fountains and eaten away to a large glowing grotto with shredded stalactites hanging within. The lava made a thunderous noise in the cone. The noise of the lake at this time was mainly a rushing sound like a waterfall, to which is added surge and thud, and an occasional quick vapor exhaust or belching noise. Small jets of flame could be detected breaking through two blankets which maintained themselves on either side of a perpetually fountaining cove at the west end. This cove was the place of uprising apparently, with surface streaming eastward away from the blankets, which occasionally parted from the bank and re-formed.

June 30, at 5 p.m., the lake showed new overflows and exhibited a swift northeasterly current bending southward at Old Faithful. The SW portion of the lake was frozen over, and the rest was covered with heavy blankets. Measurements indicated continued rise, but at this time it was relatively inactive.

July 1, at 4:20 p.m., the lava sank 10 feet, flowing with a slow easterly current. There was a slight increase in smoke. Old Faithful was smaller and less active, but there were several large, shifting fountains working near the walls. The lake had been higher in the morning. The cone at the S cove was plastered over with new lava and was active within. The streaming was mostly into the S cove. .

July 2, at noon, the lava sank 3 feet, and there was more smoke in the pit, mostly coming from the cone at the S cove. The current was slow and eastward. Old Faithful had again become very large and active, while the large shifting fountains were still in evidence along the walls.

The seismographic instruments are being set up in a cellar immediately beneath the large SW workroom of the Observatory (Wood, 1913). This cellar has walls and floor of concrete with concrete elevated piers. Both floor and piers rest directly upon a sheet of lava. Though abundant daylight is admitted to the room, its temperature varies only very slightly because in several spots its walls and floors are in direct contact with natural steam cracks. Thus its atmosphere is kept several degrees above that of the outer air.

Fortunately, the temperature in the room is practically constant, for modern seismometric apparatus is much disturbed by even slight changes in temperature.

A partition fitted with large glass panels divides the seismograph room and thus provides space for the daily routine work of changing and preserving record sheets and affords a corridor from which visitors may examine the seismographs. As the seismographs are sensitive to minute disturbances in the air about them, such as the light currents stirred up by persons moving about in the closed room, the chamber in which the instruments are isolated should not be entered unnecessarily.

Three types of seismograph are now being installed from designs by the Japanese seismologist, F. Omori.

Because of the complexity of earthquake motion, its components are resolved in the three mutually rectangular directions—N–S, E–W, and vertical—according to a well-known dynamical principle. As yet we have only one part of the most sensitive seismograph. This has been mounted to register in the E–W direction. It is a horizontal pendulum, and its sensitivity is due to the great weight of its bob, or "steady mass", and to its relatively long suspension wires, its horizontal strut, and the boom which engages its writing lever. This construction gives the pendulum a high moment of inertia and permits adjustment for a very long period of natural swing and for a high factor of magnification of earth motion. By suitable adjustments of period and magnification, this pendulum can be rendered very sensitive to distant earthquakes, or to the earth surface in its neighborhood.

The second type of instrument consists of two lighter and smaller horizontal pendulums of correspondingly less sensitivity, designed for the registration of weak or moderate, local or moderate-distance shocks. These are mounted to register E–W and N–S components of motion.

The third type of instrument is designed for the registration of "ordinary earthquakes" (Omori, 1900–1923)—that is, moderately strong shocks of local origin. It consists essentially of two lightweight horizontal pendulums capable of small magnification of the earth motion, set to measure E–W and N–S components, together with a light, vertical pendulum (a small weight at the end of a short lever kept "floating" in air by two balanced spiral springs) to measure with small magnification the vertical component. This instrument records only strong shock.

These pendulums write upon a smoked paper band wound on a drum which is set revolving rapidly by the release of its driving clock the instant the earth motion becomes great enough to disturb sufficiently a sensitive starting device which closes an electric circuit thereby operating the necessary electro-magnets. Because of the rapid motion of the drum a chronographic mechanism is provided which marks half-second intervals on the moving record. Time of starting is printed on the dial of the station clock by an ingenious movement of the dial itself, also actuated by an electro-magnetic device. An alarm bell is also set ringing when the starting mechanism is disturbed. Because of the great delicacy and sensitiveness of these instruments to vibrations and to warpings in the rock basement, to changes of temperature and to currents in the surrounding air, their complete adjustment requires time and patience. After setting up they need to "settle" to bring their various parts into mechanical adjustment to the static strains which act on them. Then for their registration to be of most value, the periods and magnification factors of all the instruments need to be adjusted so as to be approximately equal, or equivalent, to each other and to the standards adopted in other seismographic stations. This "tuning up" requires time, and several weeks elapse before the work of this seismographic station can come upon a routine basis (Pl. 4).

Crisis of Violent Effervescence:

After the lowering of June, and the sharp recovery after solstice, the period about July 12–14 produced an enormous quantity of burning gas and heat through the lava pool. This was one of three fountaining culminations, all associated with solstice—namely, January 1910, January 1912, and July 1912. All these were followed by pronounced lowering, as though the escape of vesiculating gases was caused by a lowering of the magma beneath. As Day has pointed out, the greatly increased number of simultaneous fountains, or centers of effervescence, corresponds to rise of temperature in each fountain measured with optical pyrometer. As every fountain is a center of oxidizing carbon monoxide, sulphur, and hydrogen, and is also a center of gas emission, more fountains mean increased volume of volcanic gas, and the pyrometer measurement shows that higher temperature accompanies such increase of volume. In other words, the escape of increased volume of reacting gases heats the lava to liquidity. The occurrence at solstice, with some lag after the maximum tidal effect, suggests a solar control of change of stress in the deep east-west crustal fracture under the Hawaiian chain along the equatorial protuberance (Wood, 1917b).

Week Ending July 11, 1912

The lava lake is 196 feet below the rim of the pit, and for the last week it has been more active and higher than since the high rise in December and January. Its chief characteristics are, for the last 9 days, its steady rise of 51 feet, its greatly speeded current running from 6 to 8 miles an hour, the minimum volume of smoke, the hundreds of small fountains and numerous large shifting ones which cover the entire surface of the lake, and the intense heat which is nearly unbearable to an observer standing at the edge of the crater.

The following are the daily levels of the lava below the east rest house:

		Feet	
July 5,	8:00 p.m.	about 194	
6,	4:30 p.m.	204	
7	5:30 p.m.	202	(Fig. 2)
8	5:00 p.m.	197	
9	5:45 p.m.	196	
10	4:00 p.m.	201	(below N station)
11,	10:30 a.m.	197	(Fig. 3)

July 5, at 8 p.m., the lake was overflowing, covering the floor of the pit. The surface of the lava was a mass of boiling fountains, the greatest activity being along the edges where large shifting fountains played. There was a strong easterly current.

July 6, at 4:30 p.m., the lake had grown more active. The rate of the E-flowing current was estimated at 6 to 7 miles per hour, there were more bubble fountains and very large shifting ones about the border. Old Faithful burst in immense fountain domes. Overflowing was in progress.

July 7, at 5:30 p.m., there was very little change in the lake, except that activity continued to increase, the current streaming into the S cove, appearing to rise along the N walls. There was great fountain activity at the W end where some of the surface streaming arose, and major overflowing was E and SE.

July 8, at 5 p.m., the lake was a little higher with very swift eastward current, and the bubble fountains increased in size and number so that they were rapidly approaching in dimensions the large fountains characteristic of normal activity. Flows were flooding the entire floor around the lake. From time to time there were slight shifts in the directions of surface streaming.

July 9, at 5:45 p.m., the lava reached its highest point. It displayed an unusually swift northward current rising along the south walls, flowing N, E, and SE, the skins sinking E and W and along the N banks. The surface was covered with more and larger fountains. The swiftest current was recorded on this date—8 miles per hour. With reference to the banks, the lake seemed a little lower, but this was not confirmed by the measurements.[3]

July 10, at 4 p.m., the lava had sunk 5 feet. The current arose toward the SW and NW, flowing toward and sinking at the S cove and near the middle of the N side of the lake.

July 11, at 10:30 a.m., the lava had risen 4 feet, with the current arising in the S, flowing N, and diverging sheaflike in the middle of the pool W, N, and E, the surface layers being partly engulfed in Old Faithful and otherwise bombarding the northern, eastern, and southeastern shores. The lake measured 550 feet long NW-SE by 325 feet wide NE-SW. From 5 p.m. to 9 p.m., the lava was boiling all over the surface of the lake in hundreds of large fountains with an incessant rumble like the noise of a large waterfall. Generally the streaming was from S to N, but incessant changes took place in the rush of surface currents. There was overflow S, E, and W. These flows, as for example at the SE end of the lake, first rush out in a flood, blacken on the surface almost instantly, and then glow only around the rims of the individual flowing lobes so that the glow pattern at night appears like a network of cracks. A wide river of overflow in the middle of the SW bank tended to skin over directly across the torrent, concealing it under a black blanket at the edge of the lake. Here the lines of streaming are longitudinal or fanwise. Farther down the stream, transverse festoons formed on its surface. From the upper skin which protruded over the lava of the lake, lines of streaming showed motion of the lake's surface directly away from the overflow. This demonstrated the tendency of liquid lava to crust over at a source of uprising, a characteristic observed in Kilauea many times. Whatever causes this somewhat unexpected phenomenon, the convectional circulation of the lake is maintained by the establishment of such places of uprising of the melt. A large patch of skin with small bubbles blistering it and a ragged edge from which the surface currents radiate outward is always an index of rapid rise, in contrast to places like the region of Old Faithful, where intense fountaining is accompanied by downrush and engulfment of skins.

Old Faithful could be distinguished as the largest fountain, frequently exploding in three or four great domes. Many of the hundreds of other fountains were quite as large as Old Faithful is at times of normal activity. Measured intervals between Old Faithful explosions were 50, 15, 45, 80, 15, and 30 seconds. The tendency to a secondary interval of about 15 seconds was very marked. The other fountains frequently migrated like floating bodies across the pool with the current, suggesting that each fountain represents a large gas bubble confined beneath the moving surface stratum, that stratum being denser and more viscous than the layers below, and so temporarily confining the rising gases from the lower layers. Old Faithful differs from the migrating fountains in that it is the center of convergence of such migration, probably over the main vertical conduit which lies beneath the lake, its stationary position being maintained by downflow of the heavy surface layers toward the middle of the conduit, the lighter and hotter convectional matter generally rising laterally or peripherally. The rapid radiation and blanketing over uprising currents in the vertical circulation is probably due to the fact that the fluid there comes nearest to being a perfect foam. Thus, while lightest in the convectional circulation immediately beneath the surface, it is also most rapidly and perfectly cooled by gas expansion and equable radiation on coming in contact with atmospheric pressures and temperatures. It flows evenly, loses gas by the bursting of millions of minute bubbles, and freezes

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[3] The banks were rising, a fact discovered for "bench magma" or epimagma later.

more quickly than the fluid of the fountaining areas which has become denser and irregularly vesicular.

On this night there was surface flow away from a quieter spot in the vicinity of Old Faithful to the N, E, and W. In the S this tendency was combated by a northward flow from the SW bank. Probably the Old Faithful locality also became a place of temporary uprising.

Spatter ramparts were built at the edge of the lake SE, NE, N, and NW. To the southward there were high glowing cracks 40 to 50 feet above the lake.

Volcanic Tremors:

The newly installed instruments began to reveal a quick-period tremor in the ground at the edge of Kilauea Crater that was sympathetic with the increase of violence at the fountaining. This is quite distinct from true microseisms, which are slow motions. Experience later showed that this microtremor is a volcanic vibration that fluctuates at Kilauea with the increases and decreases in lava fountaining in Halemaumau. The subsequent classification of short-period tremors (0.2 to 0.5 seconds) at the Observatory indicated that those due to continuous lava fountaining, or frictional rush of gas upward through the lava column, produced a uniform sinusoidal autograph at the seismograph pens. This we called "harmonic tremor". Another kind, of similar period but less rhythmic, was called "spasmodic tremor". This last appeared to be miniature earthquake. This again became the subject of a subclassification called "avalanche tremors", where a distinct correlation was obtained between a succession of avalanches in Halemaumau that generated miniature shocks at the instruments 2 miles away. Investigation of these movements needed careful separation from very feeble earthquakes themselves setting loose the avalanches. As an artificial disturbance such as a quarry blast or the passing of a heavy road tractor can also set up tremor, one must be cautious in evaluating these records. Volcanic tremors noted by the Japanese seismologists have qualities and subdivisions like those in Hawaii (Omori, 1900–1923; 1911; 1913; 1920).

WEEK ENDING JULY 18, 1912

July 12, the lava reached its high level for the recent period of extraordinarily intense activity, remaining at nearly the same height until July 14, when at the time of new moon it began to subside rapidly, falling on three successive days 21, 28, and 20 feet each day. The lake on July 12 measured 550 feet by 325 feet; caving during subsidence lengthened it to 575 feet by July 18.

The following were the levels of the week below the rim:

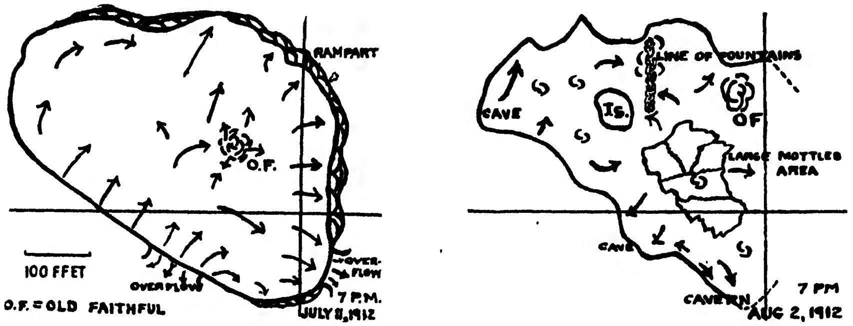
	Feet
July 12, 4:00 p.m.	192 below N station (Fig. 3)
13, 11:30 a.m.	197 below N station
14, 10:30 a.m.	219 below N station
15, 11:45 a.m.	247 below N station
16, 1:00 p.m.	267 below N station (Fig. 3)
17, 3:30 p.m.	277 below E station
18, 10:30 a.m.	280 below E station

The lava is now nearly stationary and has been so for 48 hours.

The afternoon of July 11 (Fig. 3) the fluid was boiling over its entire surface with tremendous fountains and nearly without blankets. About 400 fountains dotted the surface at the same instant. The process was continuous and has been so for the last 10 days. The noise was an incessant rumble heard at the Volcano House nearly 3 miles away.

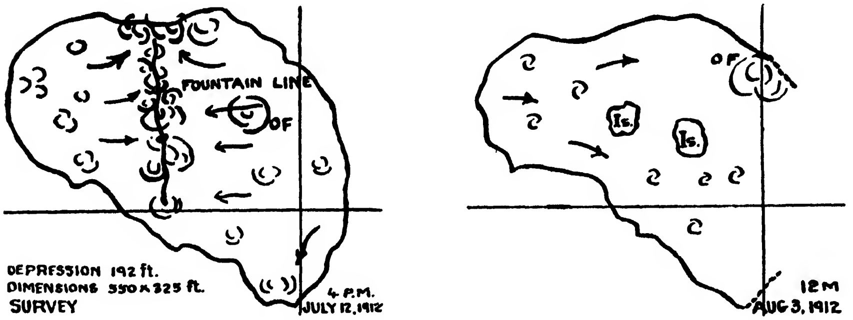
Great volumes of visible bluish vapor were emitted from the fountains, especially along the heavily bombarded walls. This increased during July 12 and 13. During all this period of activity, traveling fountains or lines of intense fountaining across the pool have been observed wherever the warring surface currents meet, the impact of two currents determining a line of down-sucking and great liberation of gas. Incessant changes take place in the rush of the surface currents, and the wall to which they rush becomes a place of violent bombardment, erosion, and caving. The spray built up a spatter rampart all around the pool during the beginning of the ebb, but especially on the N wall, where on July 14 it stood 30 feet above the lake.

During the rapid fall of those days, a line of fountains frequently formed straight across the pool from NE to SW, the E and W currents meeting in what seemed like two downpouring merging cataracts. The sound was much like a heavy waterfall. With the sinking, which left nearly vertical



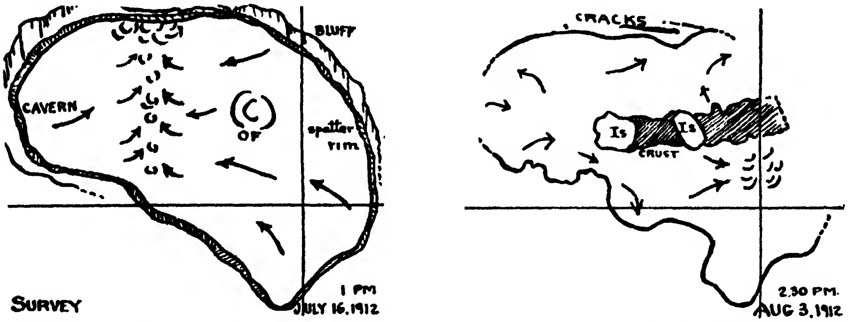
a. July 11; streaming to northeast ramparts.

d. August 2; island formed and radial streaming from crust.



b. July 12; streaming from east and west to travelling fountains.

e. August 3, noon; two islands.



c. July 16; same with lowering in cup.

f. August 3, 2:30 p.m.; islands, crust and smoke, strong subsidence.

FIGURE 3.—*Lava lake maps July–August 1912*

(*See* Figure 1.)

walls, big stalactites of lava appeared in ranges, especially at the W end where they enclosed cavernous places.

During July 15 and 16, the lake continued to sink, leaving horizontal and stalactitic scars on a vertical wall, with hardly any decrease in activity and much increase in fumes. These began to pour from old vents in the high walls and cracks at the foot of the cliffs around the outer edges of the 200-foot bench. This bench slumped fully 20 feet during the week; on July 18 it was at least 207 feet below the rest houses, whereas the ramparts were above the lava on July 12 when the latter was only 192 feet down. The fuming cracks around its outer borders are evidence of such slumping.

July 17, at 9 a.m., the lava was 70 feet below its ramparts of a week ago, boiling hard from scores of fountains and bombarding its N wall. There were five or six stalactite levels down some 40 feet, and under that a spatter bench rounded outward, marking the relatively stationary lava. Strong fumes rose from the N wall where the lava was bombarding the shore. No fumes, however, were visible above the hundreds of fountains dotting the surface of the liquid lake though some bluish vapor from the fountains may have been sucked along the surface toward the N. The higher inner wall was fuming S and E.

The bench, around its periphery, had cracked away from the older wall, and along the base of the north cliff of Halemaumau a line of streamers of heavy white vapor pushed upward from these cracks. More irregular cracks were vaporing along the S wall, and the old southwestern fuming patch high up the inner wall of Halemaumau had re-established itself, coating a tumble of rocks with sulphur. A higher solfatara appeared under the high western cliff of Halemaumau. On the bench over the lake was a velvety yellow-brown sublimate S, SE and SW.

The current was very strong from the E, rarely being met in lines of fountains by the weaker east-flowing currents. At 9:15 a.m., the attack on the N wall caused a collapse, brown dust and fume arose, and a wave crossed the lake to the SW shore. This caving revealed red heat in the bench beneath, some 60 feet above the pool. About 30 feet above the pool pasty red lava emerged from the stripped wall and flowed downward 4 or 5 feet before congealing. This appeared to be some of the still fluid lava of the flows of a week ago, confined within the bench and released by the caving. Close observation showed that this was not wholly liquid flow, for much of the incandescent material was scaling off the surface of the cliffs in a solid or semisolid condition like dross from a blacksmith's forge. In one place, however, the movement was distinctly a stiff flow.

At 9:20 a.m., a shallow cavern under the W end was overhung by stalactites. A crack 6 to 8 feet from the edge of the bench on the N side of the lake suggested that caving was imminent. The surface streaming at this time was from E to W, and one E-W line of traveling fountains was seen.

A roundish niche on the SW part of the bench with its floor 30 or 40 feet below the edge extended back 50 to 60 feet. Here was the main uprise, overflow, and inflow of July 11 and 12.

July 18, in the morning fumes obscured the pool. The fountains were numerous but smaller. Occasionally the fumes are carried over the edge, and a suffocating whirlwind arose, both July 17 and 18.

At the Observatory two of the seismographs, mounted but not yet recording, show microseismic motion, the writing pens oscillating continuously, both N-S and E-W, several millimeters. This motion was not noticed before the present high-pressure period of activity at Halemaumau began, but it is not certain whether the tremor is an index of that activity. Experiments with microphone in the seismograph cellar reveal sounds somewhat sympathetic with this trembling.

The past fortnight has been remarkable for excessive emission of gas from the lava column, and the temperature of the lava at the surface has been unusually high. From July 9 to 13 it was necessary to shield the face from heat with masks in watching the pool, although the liquid surface was nearly 200 feet down. The night glow on clouds has been seen at Hilo, Pahala, in Kona, and faintly even at Lahaina.

WEEK ENDING JULY 25, 1912

The activity in the lava lake has decreased considerably, the lake having sunk to a depth of 315 feet from 280 feet on July 18. The currents have slowed down to about half their former speed, and although the lava is quite active in fountains it cannot compare to the lake of 2 weeks ago.

Walls 100 feet high surround the lake, and the entire floor of the pit has sunk 20 or 25 feet, leaving large cracks and upheavals over the surface. At the S cove, hundreds of tons of rock have fallen into the lava.

The average depression of the lava for the week was 295 feet. The following are the daily lava levels below the E station:

	Feet
July 19, 9:30 a.m.	283
20, 6:15 p.m.	273
21, 6:00 p.m.	293
22, 4:00 p.m.	299
23, 5:30 p.m.	315
24, 6:00 p.m.	310

July 19, 20, and 21, there were few changes in the lake, except for its slight differences in elevation; there were strong shifting currents and tremendous volumes of smoke, often so dense as to conceal the lava.

July 20, at 6 p.m., the fountains became less numerous, and the lava was active along the S walls. The surface streaming was southward. At 9:30 p.m., the flow was swift from N to S with fountains. Patches of skin parted from the N side of the lake, shore bombardment was in progress SW and E. The S cove exhibited a narrow fingering chasm at the end of a V-shaped bay. The SW wall appeared built up by lava splashing, in contrast to the other walls which had vertical sides made by caving. Within the chasm at the extremity of the S cove and under the bench, an opening like a shaft rose through the bench, with glowing and spurting lava or sparks. Strong fumes rose from the walls. The pool was luminous, but the heat on the rim of Halemaumau was not great. Occasionally a blanket formed over the surface of the lake. The SW niche remained intact, and many spitting fountains roared continuously. Old Faithful could not be identified from the E station, probably because of the intervening bluff.

Still fewer fountains played July 22, at 4 p.m., and the current changed to a steady SE streaming. The floor had sunk again about 10 feet, and the walls around the S cove had been cracking or caving.

July 23, at 5:30 p.m., the lake showed increased activity with a very strong shifting current, usually southerly, and there was increase in fountains with less smoke. A large piece of the S wall fell in, leaving the newly exposed under layers of the floor glowing red in many places, while at a few points molten lava oozed out into the lake. The place collapsed where the open shaft had been.

There was much less smoke July 24 but otherwise no change.

July 25 the activity was decreasing.

WEEK ENDING AUG. 1, 1912

The past week has been one of sinking of the Halemaumau lava column with heavy falls of debris from the walls, strong ebullition with many fountains, and the development of first an island, then a peninsula, made of overturned blocks of the southern, tumbled bench. The bench, formerly at the 200-foot level, has also subsided so that it has opened many fuming cracks. The fumes obscure the pool much of the time in daylight. The conditions recall those of January, when there was rapid falling after the high rise of December.

The levels below the eastern rest house have been approximately as follows:

	Feet
July 25	315
26	310
27	about 320
28	about 325
29	about 330
30	unrecorded
31	359

July 28 Dr. Charles W. Eliot, President Emeritus of Harvard University, visited Halemaumau and wrote in the Volcano House book, "The most wonderful scene I have ever watched."

On the evening of July 26, visitors at the eastern station were startled by a very heavy tumble of a large portion of the S bench into the pool. Part of this material formed a long oval rigid island, its greatest length extending E and W, about the middle of the pool. More avalanches took place on July 27.

On the evening of July 28, the island lay like a stranded whale with strong streaming of the lava both N and S. The streaming incessantly changed, and the fountains boiled by scores. Occasionally a whirlpool formed W of the island with rotation counter-clockwise as one looked down upon it, and strong fountaining at its center, which appeared to be sucked downward. The S end of the pool forms a V with a cavern at the apex filled with the pounding fluid lava. There was a crack emitting a large sheet of bluish flame on the SW wall on the evening of July 28, and glowing spots still higher S and W. All around the edge of the cracking and caving bench dense whitish and yellowish fumes arose, and the SW wall of the inner pit immediately above the lava exhibited a wild tumble of crags and downslipping fragments. A report of the late evening of July 28 described the island as submerged, probably by the rising of lava around it. The talus under the 1894 bench NE followed by Day and Shepherd in their descent May 28 had slipped to a lower level.

July 29, a peninsula appeared along the SW wall at its base, elongate to the NW, with solidified crusts between it and the SW bank. Fumes increased.

At 3:30 p.m. July 30, the fumes greatly interfered with the view. There were active fountains N, NE, and S, and spatter ramparts were built against the peninsula of the day before. Two pools of fluid lava were seen along the opening between the peninsula and the SW wall. Old Faithful has not played regularly nor recognizably during this week. The lava was rising and sinking a foot or two at a time in short periods. No flames were seen. The NE bank was caving, and in general the pool appeared lower.

Between 3 and 5 p.m. on July 31 a spatter bench had appeared on the N bank, implying that the subsidence of the bench must have kept pace fairly evenly with the sinking of the lava. Large pieces of the NE wall fell in during the afternoon, and the roar of the many fountains over most of the pool had increased, together with some increase of heat and glow. There were cavernous hollows with stalactites at the level of the lava on the W and S ends. The walls were being bombarded principally E and N, and frequently the streaming was radial from a quieter spot near the middle of the pool, suggesting rising. The level was measured with some care, and the depth of the surface below the rest houses was the lowest of the year, 359 feet. The last low level was 323 feet June 24, and there was a similar subsidence, imperfectly measured, on January 29, recorded as 339 feet. Old Faithful was not identifiable, and the SW peninsula was still in place.

August 1, at about 1:48 p.m., the seismographs recorded a local earthquake.

WEEK ENDING AUG. 8, 1912

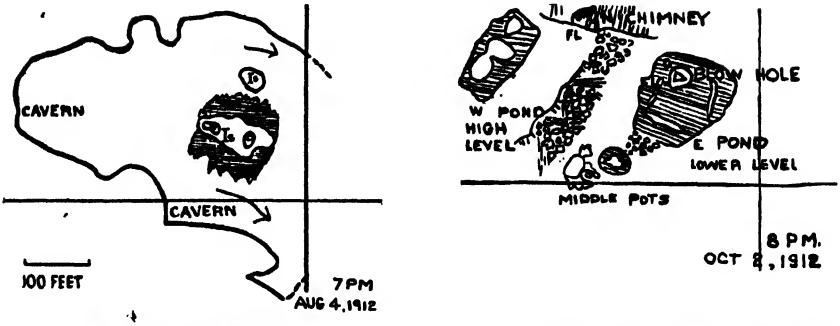
The week of August 1 to 8 has shown continued falling of the level of Halemaumau, and caving walls. The record of subsidence of the past month, from the high level 193 feet below the station on July 12, to the low level today 407 feet below, has proceeded as follows:

	Feet
July 13 to 17, falling	19.7
18 to 20, rising	1.3
21 to 23, falling	14.0
24 to 26, rising	1.6
July 27–Aug. 1, falling	11.6
Aug. 2 to 8, falling	3.8

The following were the levels of the past week below the E station:

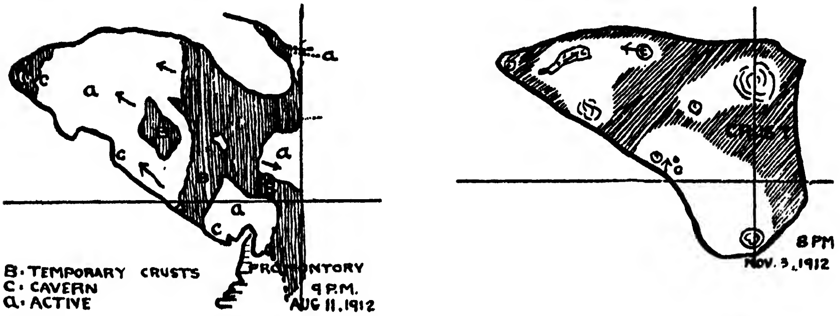
	Feet
Aug. 1, 5:00 p.m.	380
2, 7:30 p.m.	380 (Fig. 3)
3, noon	387 (Fig. 3)
4, 6:00 p.m.	393 (Fig. 4)
5, 7:00 p.m.	394
6, 11:00 a.m.	400
7	obscured by fumes
8, 10:30 a.m.	407

The fumes during the daytime have been so dense that generally the lava pool has been visible only from the E station for short glimpses. Commonly the evening is better for observation, both because of a change in the wind which cleared away the fumes and because of illumination from be-



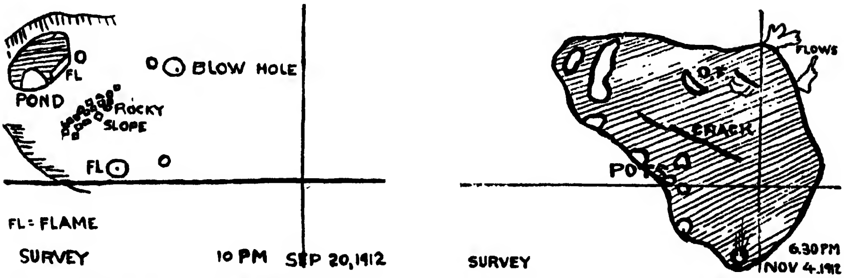
a. August 4; three islands.

d. October 2; different levels, two ponds, chimney and pots.



b. August 11; crusting over and westward streaming.

e. November 3; crusted lake.



c. September 20; sunken pond, flames and blowhole.

f. November 4; crusted lake, pots and overflows.

FIGURE 4.—*Lava lake maps August–November 1912*

(*See* Figure 1.)

low. Changes in outline of pool and in streaming of surface currents have been numerous, and islands have formed, apparently as a result of the falling in of large fragments of the bench, or of revealing submerged fragments by subsidence of the liquid.

August 1 the lava had sunk 21 feet since the previous day, and where a peninsula had been on the SW wall there appeared an angular bay. The lava streams were pouring radially from the middle of the pool, where the cooler blankets mottled the surface, and many fountains boiled along the shores. There were no islands. The SW slope had caved in and exhibited a talus. Dense fumes obscured the view.

At 7 p.m. August 2, there was no measured change of level of the pool, but a nearly circular islet had appeared in the west-central part of the lake. There were cavernous places along the shore W, SW, and S, with heavy lava stalactites; the radial surface streaming was from the middle part of the pool east of the island, Old Faithful fountain was identifiable playing occasionally on the NE bank, and a second angular bay along the W–SW bank suggested a possible source for the block which probably produced the island. The activity, as ever during the past month, was intense, but the number of fountains has been decreasing, yellow giving place to red, indicating lower surface temperature. Fountaining activity was strong NW, SW, and NE and probably under the ledge in the S cove. East of the island traveling fountains formed along a N–S line. The pool was now so low that the 200-foot bench cut off all view of the E side of the pool from the E station. High glow holes were noted at several places far above the level of the lake. The fumes were very dense.

August 3 was peculiar at Kilauea in that the day opened with rain and thunder. This rainy spell was accompanied by a south wind, an unusual wind at this season, as generally the northeast trade prevails. At noon a glimpse of the lava pool revealed a second smaller islet east of the first one, and strong eastward streaming of the lava past the islands. At 2:30 p.m. strips of crust joined the two islands and the eastern shore. There was glowing lava in crevices at several places on the high slopes of the southern bench above the pool; this bench and the eastern one are much broken and tumbled.

On this day ebullition was intense, the streaming was various and irregular, Old Faithful was playing against the NE bank, and avalanches were heard. As sinking has been steady and rapid for the last few days, the bench cracking and subsiding with the lava, the islets are undoubtedly submerged blocks formed by the tumbling in of the SW wall. There were on this day two notches corresponding to the two islands, whereas, on August 1, there was only one notch in the SW bank. The NE wall also has caved so that the bench is narrower there. The SW high yellow fuming patch is like that of 2 months ago. The S cove is less active than a week ago, and the chimney over it is jumbled. The NE wall of Halemaumau at its base has a row of fuming cracks in a line where the cliff joins the bench. The fumes were so dense that, with the SW wind blowing, the only view of the bottom area was from a narrow stretch on the E rim.

August 4 showed light winds, the vane at the Observatory near the Volcano House recording E and ESE wind, but the fumes from Halemaumau were blowing at times northward directly toward the Volcano House making a curtain over the Kilauea floor. At 7 p.m. the activity was strong with many fountains. Just above the south cove in the bank a caldron appeared with glowing lava splashing within. Streaming was eastward. A change had taken place in the islands, possibly explained by the merging of the two islets and the formation of a small new island by the breaking away of a spall from the N bank. The two islands were now aligned N and S, whereas yesterday they were E and W, and, moreover, the southern island was now more than twice as large as the northern one. This larger island showed two pinnacles, the higher at its W end. Today the two-pinnacle island has skins formed against it N and S, which continually break away from it. The caverns W and SW showed stalactites hanging within.

On the evening of August 5, Halemaumau presented a remarkably varied spectacle. The northern island was replaced by a peninsula, probably by subsidence of the lava around it, a swift current flowed around the eastern end into a violently boiling whirlpool in a small V-shaped cove NE of it, and occasionally a fountain burst violently through this whirlpool—possibly Old Faithful. There were now three islands in the eastern half of the lake, at least one of them new. Streaming was E and W from a middle area of mottled pattern.

Around the end of the northern peninsula, the surface current rushed with extraordinary rapidity fanning out in a continuous whirlpool through which occasionally a fountain exploded. A current poured out from the inner end of the cove back of the peninsula and joined this whirlpool where it revolved at the mouth of the cove. The effect of downsucking of the stream which poured from between the northern islet and the peninsula was as though the lava were pouring over an edge into a void to form a cataract. There were heavy stalactites around the lake. A flaming crack flared southwest of the pool, and three or four glow spots appeared in the 200-foot bench to the SE. The highest luminosity in the lake and most of the small fountains were at the W end.

August 6, there was no great change, but the many fountains were active and noisy as they have been since early in July, but with greater development of the mottling pattern of blankets. The SE island near the E bank appeared higher.

August 7 and 8 produced no important changes. Crusting increased around the islands, connecting them with the shores both NE and SW and at times dividing the pool. The fumes about the edge of the pit are partly brown with sulphur, partly white. The area outside Halemaumau, known as the "Devil's Kitchen", shows less vapor, the change being coincident with this period of subsidence and strong vaporing within the pit.

At 11:50 a.m., there was a loud avalanche at the W end of the pit, and another at the SW at 5:30 p.m. Heavy white fumes greatly obscured the view.

WEEK ENDING AUG. 15, 1912

For the past week fumes have risen in greater volume from the cracked and crumbling ledges which rim the lava pools, almost continuously curtaining the view during hours when the pit has been under observation, except in the evening of August 11.

During this week one reliable measurement of the depth of the lava was secured:

August 12, 6:30 p.m. .... 441 feet below E station

Rough measures August 10 and 11, compared with this reliable value, were inconsistent.

August 9 in the evening, the lava in Halemaumau was sinking, showing large stalactites and overhanging ledges on the W and SW. Ledges about the pools slumped, and small avalanches fell from neighboring walls. Crust was forming on the surface in greater amount than at any time since the beginning of the recent period of remarkable ebullition, uniting the N peninsula, the islands, and the SW bank, so as to create two pools E and W. The crust cracked, floated off, and foundered, with streaming of the lava westward in the west pool and eastward in the east pool. In the darkness, glowing spots could be seen at considerable heights on the S wall and also at the rear of the former 200-foot ledge under the SW wall. A collapse SW broke in the crusts W of the island. The V-shaped cove between the peninsula and the NE wall, on August 5 the site of Old Faithful, was now very narrow, and the current around the end of the peninsula was no longer discernible.

August 10, the lake was almost totally obscured by the fumes.

For a few minutes at a time in the evening of August 11 the smoke cleared. At this time the evolution of fumes seemed less, and the glow of the lava appeared brighter. As seen from the E station the lake was divided by bands of strong crust into a large pool on the W, in vigorous ebullition, and on the E into two smaller pools dotted with continuous fountains. Streaming was westward in the W pool and eastward in the E pools. Small avalanches were heard. At 9 p.m. the crust on the E side of the W pool was breaking away and floating westward (Fig. 4). Over the W end there was a bridge of crust with an open glowing pot above. There were caverns under the western crust, on the S side of the western pool, and on the SW side of the southern pool. The northern peninsula was still in place but encased in crust except for a small active area at the mouth of the cove NE of it. In the eastern pool streaming was eastward.

Brief glimpses of the lake in the afternoon of August 12 disclosed no important changes. A spatter rampart at the SW indicated a transient stand of the lava level at the measured depth—441 feet below the E station. Strong single hisses of gas were heard. North of Halemaumau the high cone of "Pele's Kitchen" was visibly steaming. The glowing pot at the W end of the lake appeared today to be a chimney in the wall. August 13 fumes obscured the lake.

On the evening of August 14, glimpses showed the lava apparently sinking, for stalactites could be seen dimly. Rock fell occasionally from the walls. At intervals the ebullition was vigorous; occasionally there was an escape of gas with a shrill hiss.

On the morning of August 15, infalls of rock from the walls were larger and more frequent.

A point of interest is the discovery, at sunset on August 9, of two "steam jets" rising from a region beyond the skyline on the northeast profile of Mauna Loa as seen from the Observatory. These are in the direction N 77° W from the Observatory. These steam jets have now been seen on several occasions. They are small and can be seen clearly only for a short time just before and after sundown. It is uncertain how long they may have been active. They may be vapor outlets of considerable magnitude.[4]

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[4] Experience later showed these to be weak steam cracks revealed, at this season only, by the position of the sun in the evening.

A local earthquake, distinctly felt at Waiohinu, was sharply indicated by the seismographs at about 3:07 p.m. H.S.T. on August 11. No seismogram of the shock was obtained because the instruments are not yet in final adjustment. This earthquake was possibly perceived as a feeble swaying at the Volcano House. At the Observatory it was not sensibly perceived.

Summer Routine 1912:

Messrs. Jaggar and Dodge on August 15 left the Observatory for an expedition to Mauna Loa, Hualalai, and Kohala. Mr. H. O. Wood wrote the reports. Mr. F. B. Dodge completed his work as assistant at the Observatory September 1. The seismographs were now settling down but were not yet recording regularly. The "ordinary seismograph" referred to as registering the earthquake of August 24 is a complicated instrument touched off by a strong-motion earthquake, ringing a bell, starting rapid rotation of the drum, and necessitating change of paper and resetting for each earthquake recorded. It was later discarded as unserviceable for this station. The surveying at Halemaumau was repeatedly improved during this year. The implements first used were Brunton compass, alidade and plane table, and surveyor's transit, the latter replacing plane table after the first 3 years. No attempt was made to rely on the compass needle, which on this highly magnetic basaltic rock exhibits great changes in declination in short distances. Throughout 1912 and for about 3 years thereafter Halemaumau pit emitted dense fume and vapor, so that surveys were often impossible in daytime, and much of the measurement was directed at glowing outlines of the lava lakes seen at night from fixed stations on the rim of the pit. Reliable measurement was dependent on the location of monuments set in concrete and located by a trigonometric net from bench marks of the U. S. Geological Survey. Meteorological observations as a volunteer station of the U. S. Weather Bureau were started soon after the Observatory was founded, in order that correspondences among rainfall, temperature, humidity, or barometric pressure and volcanic phenomena might be identified. As the fluctuation in density of fume column, rising from Halemaumau, as seen from the Observatory was noticeable, a daily photograph from the Observatory, looking toward the pit, was instituted, and this proved serviceable several years later when the top of the live lava column came into view and changed its position from day to day. Time service was of first importance, a solar transit and a chronometer were obtained, and a routine of sun observation by instruction from an officer of U. S. Coast and Geodetic Survey was eventually established. This is now replaced by radio time direct to instruments.

WEEK ENDING AUG. 22, 1912

The excessive exhalation of white fumes continues at Kilauea, dense clouds curling up and obscuring all the lower part of Halemaumau most of the time. During the week only one or two momentary glimpses of the lake have been had by daylight. On some evenings for short times the lake has been clearly visible. The pools remain active exhibiting ebullition with playing fountains and show no tendency to freeze over. They are, however, much smaller. Two chief pools are seen, both small, one at the extreme W, the other SE. Two or three very small pools, choked with blocks fallen from the ledges, are about the margin of the lake between these larger pools. The center of the lake is so crusted over that no fissuring has been seen in it in the past few days.

In the W pool the fountains play constantly with great energy, the gas escaping now and then with a loud, hissing noise. No constant direction of flow is maintained. The general tendency, however, seems to be a streaming to the W.

Whenever the pools have been visible during the week, lava stalactites have been seen, and fall of rocks from the surrounding ledges has been frequent. This indicates a sinking lava column. No measurements have been secured except from the E station, and of these only one, made on the evening of August 21, was accurate. This made the level below the E station,

August 21, 1912, 7:15 p.m. .... 502 feet.

A rougher measure indicated the depth

August 20, 1912, 9:30 p.m. .... 491 feet.

The lava thus has been falling during the past week.

In the evening of August 15, clear views at intervals revealed stalactites pendent beneath a spatter bench which was still forming, indicating a temporary oscillation of level at this depth. There was no marked falling of rock during this evening. In the W pool a fairly active streaming westward was noted.

Throughout the afternoons August 16 and 17, no good view was obtained—only one glimpse in a stretch of 7 hours. Heavy falls of rock were frequent. In the late evening of August 17 visitors reported a clear view. Subsidence had evidently been resumed.

In the evening of August 18, visitors reported falls of rock throughout the evening; no view was obtained.

On August 20, good views were obtained between 9:30 and 10 p.m., and measurement was made with compass from the E station. Stalactites were in evidence, rock falls were frequent and heavy, but a spatter bench was forming.

Week Ending Aug. 29, 1912

Halemaumau has not changed, and in general the crater has remained as described on August 22. Dense white fumes rise from the talus about the inner walls, generally concealing the lava pools, which have been seen dimly from time to time, especially at night, at depths near 500 feet below rim.

At 3 p.m., August 26, the only opportunity for a rough measure of depth was secured. The wind was easterly, and for the first time in several weeks a view of the interior was obtained from the old rest house and NW station. Two pools of lava were seen, one on the NW side of the bottom area, the other SE. The SE pool was seen for short glimpses and appeared the larger of the two, oval in shape, and was boiling with activity to judge by the sound of fountains and an occasional exceptional hiss. The NW pool was clearly seen, and a rapid compass survey indicated depth as

August 26, 3 p.m. .... 511 feet below W station.

The pool was L-shaped, small, and exhibited stalactites on the walls and a few fountains.

The N and W slopes leading down to this pool had assumed funnel shape, the 200-foot bench being almost destroyed, its remnants showing flat strips, seamed with fuming and sulphur-stained cracks. A rugged promontory jutted out into the floor area S of the NW pool. The isthmus between the two pools appeared to be a high mass of tumbled debris. High on the SW inner slope of Halemaumau, about 250 feet below the rim, a craterlike depression strongly coated yellow with sulphurous salts yields excessive volume of fumes.

Within 70 minutes on August 26, three falls of debris were heard, mostly from the S and SW. The first, at 2:52 p.m., was moderately loud, followed by a vigorous bubbling noise. This was heard from the N rest house where the interior of the pit could be seen down to the 200-foot bench. The avalanche was below this level. The second fall at 2:58 p.m. sounded like a single large block of rock toward the W. The third at 3:40 p.m. was also from the W and was a slide on the talus.

About as frequently, falls were heard about noon August 27, and the plash of the fountains was similar to that of the previous day, but nothing could be seen through the wall of vapor.

Between 2 and 3 p.m., August 28, with a strong NE wind, conditions were the same, but the rock falls were less frequent; only slight tumble was heard. Nothing could be seen of the bottom area.

Mr. Wood reports an earthquake of near-by origin, strongly registered by the highly magnifying tromometer designed for distant or feeble earth movement, and registered plainly by the "ordinary seismograph" designed for shocks of this character. It occurred in the evening of August 24 at about 6:16.5 p.m., H.S.T. Instrumentally it was a marked shock, but, as no one about the Volcano House reported feeling it, it ranks II to III of the Rossi-Forel intensity scale.

Week Ending Sept. 5, 1912

The measurements made during this season of fumes and poor visibility from the edge of the lava pit could not be made with telescopic alidade, as the glimpses of the pools were short and dim. Accordingly attempts to measure horizontal or vertical angles were made from time to time with Brunton compass mounted on a tripod, the horizontal angles being referred to the magnetic needle. The results of these surveys when first platted failed to check and were discordant and confusing. A year later, in 1913, work by J. W. Green of the United States Coast and Geodetic Survey (Faris, 1914) at Halemaumau revealed variations in magnetic declination, amounting to as much as 16°

on opposite sides of the pit. Every triangulation station used habitually in the plane-table surveys by the staff of the Observatory has a different declination constant. In the light of the later-determined declination values for the stations the surveys of August 26, September 2, and September 19 have been recalculated, and the corrected depths to the lava lakes are here given.

Halemaumau lava has risen somewhat during the past week. It has remained generally obscured by opaque white vapor which rolls off to leeward in great volumes.

The week has been notable for ending the long drought and the water famine at the Volcano House. That hotel is well supplied with water once more, as there was rain at night September 1 and 2, and almost continuous rain September 3 and 4.

For the past 2 weeks as seen from the Observatory, the pit has emitted dense fumes, and the glow on the fumes at night has been orange red. For the past week, little has been seen through the smoke, but there has been no marked evidence of change indicated by noises or other symptoms.

From 8 to 10 p.m., August 29, the red glow of the lava upon the ever-rising fumes was all that could be seen at the edge of Halemaumau. Some clattering small slides of rock were heard. Besides the muffled hisses of gas escaping through small blow holes, which are characteristic of such sinking spells, there was one heavy, resonant, belching sound, as though a great bubble of gas were released from viscous lava.

There was no marked change August 30 and 31.

From 6:30 to 9:30 p.m., September 1, the pit was watched from the E station, and occasionally the southern inner slope cleared sufficiently to reveal a funnel-shaped slope of debris with dense white fumes rising from it. Three or four times during the evening a very small pool of lava could be seen under a ledge over 400 feet down the E side, and another larger western pool was seen dimly through the vapor. Faint glow to the SW through the smoke suggested the presence of a third pool in that direction. Avalanches were seldom heard at this time.

On September 2, the fumes were unusually dense and brown with the dust of many slides. The wind was NE. The hissing of gas in sudden sharp discharges within the pit was remarkable and very loud, like a suddenly checked steam whistle. This was repeated all evening. Ten of these discharged between 5:17 and 5:28 p.m. showed average intervals of 68 seconds, not unlike the intervals of Old Faithful fountain. From the E station at 8:30 p.m., during a temporary clearing spell, the southern slide-rock slope gave vent with a roar to puffs of white vapor, and the rumble of the gas escaping was followed by a slight clatter of sliding rocks. Avalanches of rock were heard all the evening, and some were heavy. The sound of avalanches had increased during the day.

At 7 and 9 p.m., views of the active lava were obtained so as to get plane-table intersection and clinometer vertical angle, the intersection being from the NE and E stations. These readings made the depth to the W lava pool

Sept. 2, 1912, 9 p.m. .... 430 feet below E station.

There was a long eastern slope down into the pit with four glowing spots upon its surface, apparently at different levels, and far below appeared a jagged and overhanging eastern edge of a lava pool within which the fluid boiled in several sluggish fountains. This pool appeared to be the western pool of the week before, and the eastern pool had apparently been obliterated by the debris of the eastern benches. The sharp hissing noises appeared to come from the region of the eastern glow spots. Slight noises of plash of fountains could be heard. The fumes seemed less acid and more respirable than usual.

On September 4, conditions were similar insofar as sounds were concerned, except that the rock tumbles were fewer, only one slide being heard from 4 to 7 p.m. The glowing lava could not be seen, but the sharp hisses could be heard about once a minute, and every 4 or 5 minutes there was a stronger one. At 4 p.m. a remarkable rainbow formed over the lava field east of Halemaumau, showing four complete spectra on the inner bow and a fainter outer one. The noise of fountains was still audible; there was dull glow on the fume cloud in the evening, and fumes were rising from the Postal Rift.

Over Mauna Loa at 6:30 p.m. on September 4, a peculiarly suggestive cloud formed over the summit region. Six successive cumulus puffs developed about over the site of Mokuaweoweo and were blown off to the SW as a train of rain cloud showing a veil of falling rain against the background. The appearance resembled the vapor cloud over Halemaumau.

The following notes by Mr. Wood suggest some perplexing movements of the ground at Kilauea, which promise to furnish material for study for some years to come:

"During the past week two well marked but very feeble local earthquakes have been registered. The first of these occurred in the early morning hours of September 2. The time of its occurrence is in doubt because the lines on this seismogram are intertwined so complexly, that it is very difficult to follow a given line from one end of the seismogram to the other without confusion. This tangle is due to tilting taking place in the earth's surface layers. To such motion the major seismograph is very sensitive. Every day its recording lever swings through a wide arc toward the east and then back toward the west as the earth tilts from its normal level. Occasionally an almost illegible tangle of interscored lines results, as on this day, making it very difficult to trace the hour of the shock. It occurred probably at about 3:10 a.m. September 2, but it would not be surprising if it were close to 2 o'clock or 4 o'clock instead. It was registered only by the major tromometer, being too feeble to start the ordinary seismograph. There is no report of its having been felt. Its intensity, then, was grade I of the Rossi-Forel scale.

"The second shock was slightly stronger, II of the Rossi-Forel scale, sufficiently energetic to start the ordinary seismograph but not strong enough to write a good record on this seismogram. The major tromometer provided a good record of it. It occurred at about 25 minutes past 12 midnight in the morning of September 4. It was a well marked earthquake of near-by origin, though not felt so far as is known. It was preceded, at about 23 minutes past 12, by a very feeble vibratory motion enduring a little over a minute, which was surely a rapid earth vibration the graph of which does not show the characteristic phases of an earthquake record.

"It is necessary as yet to give the times only approximately, as provision for the strictly accurate keeping of time at the station is not yet completed.

"It is interesting to note that ever since the major tromometer has been set up there has been noticed a constant, never-ending, jerky, swinging motion of its writing lever, through a very small arc and with a short but irregular period. Such motion as this, though usually less pronounced and less constant, is noticed at all seismograph stations. Commonly it is believed due to variation in meteorological conditions. At Japanese stations motion of this sort has been registered with periods varying all the way from 1 to 10 seconds. A cursory study of the movements here indicates that the period is usually between 3 and 4 seconds. Now and then this motion has been so strongly marked as to waken suspicion that it might be local vibration due to volcanic activity. But both in period and in strength it might well be simply the ordinary microseismic motion. Hence it is important to note that a second type of vibration is discovered present on the seismograms,—a very minute motion visible with difficulty except through a lens (though the direct magnification by the seismograph is at present 200 times), with a very rapid motion indeed, a period determined roughly at ½ second. Complete sources of information are not at hand for consultation but the writer remembers no mention of such vibrations as these in seismological writings. Whether this vibration is due to local disturbances associated with the volcano is a problem which will require time and experience for its solution."

WEEK ENDING SEPT. 12, 1912

With the termination of the long summer drought and about the time of the September new moon the lava of Halemaumau appears to be rising once more. It has been very difficult to obtain satisfactory measurements because of the fumes. There has been some diminution in the volume of the fumes in the last few days. The lava was seen on the afternoon of September 9, when there seemed to be one pool in the western part of the bottom area, with lava in ebullition and a blow hole in the eastern part occasionally hissing.

On September 5 the glow over the pit as seen from the Volcano House was dark red and dim. The fumes were dense, and usually nothing could be seen of the lava in motion.

September 8 in the afternoon, the lava pool was obscured by fumes, and an occasional slow, wheezing sound was all that could be heard of the blow hole. There was almost no noise of talus slides. The cessation of these rock falls is apt to accompany a change from falling to rising.

September 9 at 2:30 p.m., the lava pool was seen from the W station. It was in the shape of a half moon, the straight side toward the west and apparently overhanging. The blowing noises and avalanches were small on this day, and in the evening the glow appeared, from the edge of Halemaumau, to be confined to the W end, as though there were but one pool and that toward the W.

On September 11 at 2:30 p.m., the western half of the pit seen from the NW station cleared from time to time and revealed an irregular oval pool with funnel-shaped talus converging toward it. Occasional light slides were heard on the talus, and the eastern blow hole could be heard puffing every 3 seconds like the exhaust of an engine. Conditions were similar to August 20. Heavy white fumes rose from lines of sulphurous vents in the talus, the lines being concentric to the pit, and at different elevations, but especially about the level 250 feet below the edge. Some of the fumes were distinctly blue in contrast to the other jets. Bright-yellow sulphur-coated vents, larger than the others, are on benches W and S. The glows at night appear brighter, and the fumes thinner. Rock slides were heard occasionally, but there were no heavy ones. Fountains were active in the western pool, but none could be heard at the eastern blow hole, and there was no sign of an open east pool.

WEEK ENDING SEPT. 19, 1912

The week of September 12 to 18 has furnished no opportunities for measurement of the depth of the lava pool of Halemaumau on account of dense fumes and a NE wind. The marked rise continued to September 16, followed by a subsidence, but the latter has not yet been proved by anything but noises. These noises of hissing, blowing, splashing, and avalanching have been the most marked features of the week, with some strikingly sudden changes. Glimpses of the pool were had September 12, 13, and 16, but not long enough for any measurements, owing to the endless eddying veil of vapor. The following accounts of the change from day to day will show the data leading to the supposition that the lava turned from rising to sinking on September 16. When the lava cannot be seen, the noise of splashing fountains, loud or faint, is a partial guide to its depth. Puffing sounds commonly increase with sinking, as the fluid becomes stiff and clogged. Avalanches of debris always accompany a sinking, but they may perhaps take place during a rise if the inflowing magma disturbs the foot of the slide-rock slopes and engulfs or fuses the rock fragments, thus undermining the slope above.

September 12, from 7:30 to 9 p.m., three glowing spots in a group, as though vents in a spatter cone or a pile of rocks, could be seen from the E station E of the glow of the main pool. These were about the region of Old Faithful and appeared to be the "blow hole" which has been so noisy. From the rim of the pit at the E A-frame (SE station), a great eddy within the pit occasioned by the whirl of fumes blown from the NE cleared the whole SE side of the interior. Inside about the 200-foot level great volumes of white vapor rise from the tumble, and the rocks are in places brilliantly yellow with sulphur. This vapor is swept north, up and over, and sucked down again, so as to exhibit a circular swirl through the center of which often the lava glow may be seen, as though through a window. The benches of the early summer have collapsed so as to leave the SE wall sheer to an immense depth, and the caldronlike abyss, looking down near the A-frame, is wonderfully impressive in the evening. On this night the noises were not loud, the blow hole puffed irregularly, there was plashing heard from the fountains, and the glow was strong.

The next night, September 13, 8 to 9 p.m., conditions were similar, but a glimpse of the pool seen from the SE revealed it boiling vigorously, apparently at no very great depth and with a ragged edge toward the SE. A glowing spot was seen south of the pool, and the triple cavity E of it showed bluish flames. Few slides were heard, and but little blowing, but the lava fountains were plashing noisily.

The fumes as seen from the Observatory have been rising in a heavy white billowy cloud, lavender in the evening. There was some diminution in their volume detected from about September 8. At night the glow was reddish or orange, and generally weak.

September 14 the fumes appeared heavy. September 15 at 11:20 a.m., with a NE wind, the fumes, strong with sulphurous acid, filled the space above the 1894 bench and made breathing difficult even at the E rest house. Some bubbling and an occasional belching sound could be heard. No falls of rock were audible in the course of 1½ hours. Nothing could be seen from the NW or N.

September 16 at the N station, at 1:30 p.m., a roar was heard. The vapor appeared thinner, the splashing and hissing noises were louder and sounded nearer than for weeks past, and the tinkle of sliding blocks of rock was heard.

From the N side near the old rest house, slides were heard on the inner slopes as follows:

(1)	1:30 p.m.	roar and falling stones, S talus
(2)	1:40	small talus slide, S talus
(3)	1:43	larger talus slide, S talus
(4)	1:51	small talus slide, SW

(5)	1:53	small talus slide, S
(6)	1:55	small talus slide, SE
(7)	2:03	small talus slide, SW
(8)	2:07	very small rock slide, S
(9)	2:20	very small rock slide, S
(10)	2:22	another long roar with falling stones like that of 1:30 p.m.
(11)	2:24	small talus slide
	Interval	slides not recorded
(12)	*2:45 p.m.*	*talus slide, S*
(13)	*2:46*	talus slide, SW

The long steady roars, accompanied by the rattle of stones, arise from the rush of vapor through the high slide-rock vents, as on September 2. Probably lava rises along a fumarole channel under the talus, and infallen material so clogs the gas that it escapes with a rush at long intervals.

In general, the numerous falls of rock on this date suggest subsidence. At the time, there was discussion whether rising or falling was in progress. The fumes were so dense that little could be seen and many of the symptoms, such as heat and noises and fountain activity, suggested rising lava. These things could also be produced, however, by a sudden collapse of crusts revealing activity which the crusts had masked.

From the E station (September 16), the noise of fountains was loud and could be located at the eastern blow hole as well as at the large western pool. This eastern locality occasionally gave vent to greater fountain noise. Some heat from the lava could be felt on the rim. The great gulf under the E A-frame was the most open part of the pit, and here the noise of the pool was continuous and tumultuous.

In the open part of the pit S about 200 feet down were yellow sulphur patches and many fuming vents in the talus. The SE wall of the pit is vertical and very high. A remnant of the 60-foot bench of January 4, 1912, clings to the S wall under the channel at the S station, and a cracked remnant of it to the W has slid down 75 feet lower. The remnant of cable from the E A-frame was on this day hauled up, and its end was oxidized to brittle yellow and red substances, shredded out but not fused. Two high sulphur cracks SSW, about 100 feet down, have stopped fuming.

At 5:30 p.m., with the twilight, the lava pools were revealed from the SE at rare intervals. There were three pools, much higher apparently than when last seen September 13, and in the same positions as the two glow spots and the main pool of that date. The large lake was W, the next smaller SE of it, and in the blow hole position was a very small oval pool fountaining violently. This last was probably Old Faithful and identical with the triple glow hole of 2 nights ago.

The earthquake reported as felt at the Volcano House at 8:37 p.m. September 16 may have been near the culmination of this rise, as there was an earthquake May 23 at the culmination of a much greater rise.

September 17 and 18 were quite different. On September 17, at 8 a.m., there was much puffing, no avalanches, and the bottom was obscured by fumes. The fumes were gathered at the west side of the pit and diffused as a veil. The blowing sounded as though largely from fountains as in July.

At 2:30 p.m., September 18 and thereafter, a steady hiss from the E like the exhaust from the open valve of a steam engine could be heard from the N rim. Fountaining from the pit was not so strong as on September 16. Noises heard at short intervals were as follows:

(1)	2:39:00 p.m.	strong puffs and fountain Old Faithful position
(2)	2:39:30	smaller fountain noise
(3)	2:40:30	still smaller fountain noise
(4)	2:42:40	very strong whistle
(5)	2:43:10	another strong whistle
(6)	2:44:00	a long light puff
(7)	2:45:00	
(8)	2:45:40	
(9)	2:46:25	a little stronger puff

The west side was obscured by fumes during 12 minutes; no avalanches were heard. There was a thudding noise in the fountains.

At 2:54 p.m., from the NE station, the continuous hiss could be heard below, and, in addition, a great puff, like a whale snorting, came every 30 to 40 seconds with intermediate smaller puffs. Four of the greater puffs gave intervals of 30 seconds, 35 seconds, 25 seconds, and 40 seconds. Suffocating fumes eddied back of the 1894 ledge at its E end.

At 3:10 p.m., from the SE, hardly any plashing noise could be heard above the continuous hiss; there were occasional very heavy gusts like rockets often prolonged and at more or less rhythmical intervals. The plashing noises in general were from the N, and the blowing noises from the E or SE. Whether the continuous hiss was from the same vent as the loud puffs could not be determined. No visible puff of vapor could be identified with the noises. The noise was remarkably like that heard within the crater of Asama volcano in Japan in 1909 (Jaggar, 1910b). Partial clearing showed no glow by daylight. The magnetic needle at rest on the edge of the pit during the rhythmical puffing showed no magnetic perturbation.

At 3:50 p.m. from the S rim, no trace of glow could be seen.

At 10 p.m. from the Observatory, the fumes of Halemaumau in the bright moonlight reflected a very weak glow within the pit.

The change in conditions on this day suggests that subsidence began about the time of the moon's quarter near equinox, after a rapid rise at the time of new moon.

The work of the seismographs has been interrupted during the past week. The major tromometer had been gradually tuned and adjusted to have a period of practically 20 seconds with a factor of magnification of 200. Our experience with this adjustment demonstrated that this was too sensitive for the place—in particular with regard to the slow diurnal wave as encountered here—so that, as the surface tilted with the swelling of the wave, the writing index swung far too widely from its equilibrium position to yield a serviceable seismogram, free from confused interscoring among neighboring hour lines. Apparently the diurnal wave is greater here than at most stations, the majority of which are situated on continents.

Furthermore, dust was accumulating rapidly in the seismograph room, threatening to interfere with efficient working, and it was suspected that currents of air went through the room at times of high wind, causing abnormal swingings of the heavy mass.

Operation of the instruments was suspended to permit readjustment in magnification, briefly resumed to test the change, and then discontinued to permit battening and painting to seal the room.

This interruption of the routine registration has resulted, so far, in failure to register at least one local earthquake, felt by several persons, and a feeble shock with motion apparently in a SW-NE direction as noted by Jaggar at the Volcano House. By others at the Volcano House the shock was not felt. Its intensity here was, therefore, II, R-F. It occurred at about 8:37 p.m. September 16.

Four very feeble earthquakes of local origin were registered by the major tromometer on September 12. None was strong enough to start the ordinary seismograph. Hence all must be classified under grade I, R-F scale, though they were by no means equally energetic. All were distinctly registered. The approximate times were:

Sept. 12, 1912,	10:50 a.m.	feeble
	11:09 a.m.	feeble
	4:03 p.m.	very feeble
	8:40 p.m.	feeble

A shock somewhat stronger than these but still only grade I, R-F scale, was registered about 11:20 p.m. on September 13.

Microseismic undulations continue but with irregular variations in strength, as do the smaller, more rapid vibrations noted recently. Very rapid vibrations like these were observed recently in Japan—there apparently for the first time—in connection with the eruption of Usu-san in July 1910. Professor Omori (1911, 1913, 1920) there associated them with phases in the explosive eruptivity of that volcano. This occurrence supports the view that the vibrations noted here result from local volcanic activity.

On September 13, the two vapor jets mentioned in the report of August 15, as seen at sunset August 9 on the high north profile of Mauna Loa, were seen at sunrise, dark against a light background of sky, by Shepherd, and estimated by him to be three or four times as high as the neighboring conelets.

WEEK ENDING SEPT. 26, 1912

Subsidence in the lava of Halemaumau has been noted during the past week. On several evenings it was possible to see the bottom, which is irregular, with small lava pits blowing and spurting and building spatter cones at different levels. The measured depression of active areas was:

Sept. 19, 1912, compass survey, 6:15 p.m..... 501 ft. (?) to E blow hole from E rim
Sept. 20, 1912, plane-table survey, 10:00 p.m..... 593 ft. to E blow hole from E rim (Fig. 4)
Sept. 21, 1912, plane-table survey, 10:00 p.m..... 577 ft. to W pool from E rim

September 19, at 6 p.m., three main luminous areas could be detected through the fumes, S, W, and E, and there was less continuous blowing than on the previous day. Fountains could be heard splashing about the western pool, the eastern area was clearly a noisy blow hole occasionally flaring up brightly, and the southern glow spot was small. From the blow hole occasionally the noise of falling lava blobs splashing on the rocks was audible. This is the process of making "blowing cones" so frequently referred to in the old accounts of Kilauea. The western pool is triangular and larger than the others. Stalactites from the back drip lined the orifice of the blow hole. Between 7 and 7:30 p.m. a wind eddy made by a light breeze from the NE opened the bottom to view; rocketlike jets of lava spray were thrown at least 100 feet obliquely upward from the eastern blow hole. The larger W pool was boiling sluggishly, and as the fountains burst a hissing rush of vapor came from them.

On September 20 a new trigonometric station was set up near the E A-frame, hereafter referred to as the "SE station", and the other stations were repaired and the posts painted white. Between 8 p.m. and midnight a plane-table survey was made with lanterns as station markers, and the following depths from the E rim are the first reliable measurements which have been made since September 2:

	Feet
From SE station to W pool	583
From E station to W pool	571
Average depth of west pool below E rim	577
From SE station to E blow hole	593

No rock slides were heard on this day, nor have any considerable ones been heard this week, implying a stationary lava column. On September 20, in the morning, the puffing sounds were prolonged, lasting from 20 to 30 seconds and recurring every 10 seconds. At 8 p.m. the bottom area was plainly seen (Fig. 4). The western pool had crusted over and subsided since the previous day; two holes (1 and 2) showed surging lava at its E border, one of them emitting blue flame (2), and a vertical wall was seen to overhang the pool on the W. The blow hole E (3) was a complex of fissures in the floor, with one larger aperture ejecting the rocket spurts which fell thudding, often ending with a sheet of lava which spread like a leaf and slopped over the rock N of the hole, retaining incandescence for 1 or 2 minutes. There appeared to be a bench overhanging the eastern end of the floor, seen dimly from the E station as a ragged edge in the foreground. Sheets and spears of flickering blue flames appeared near the S cavity and on the border of the crust over the W pool. The scene was spectacular, with veils of brown and white fumes lifting and falling, while sporadic spurts from the blow hole made a bright flashing orange glow over the whole vapor cloud, noticed even at the Volcano House. This, the Old Faithful locality, was by far the most conspicuous feature of the floor; here had been the triple glow spots of September 12–13, the small oval pool of September 16, and the noisy blow hole of more recent dates, exhibiting a roundish pot September 19. This pot had become constricted with spatter accretion, and through the orifice every 30 or 40 seconds, but not regularly, a spurt of lava spray, inclined to the north, was ejected with a rocketlike noise to heights estimated as sometimes over 100 feet. A smaller spurting hole lay east of and adjacent to the larger one. The sheet of liquid, vomited northward over the floor from the larger blow hole from time to time at the end of a spurt, was gradually building a cone (Fig. 4). There was a small glowing pot at (4), a hole at (5) not splashing visibly but glowing within, with a continuous spear of blue flame playing through a crack beside it, at (6) a new glow hole which opened during the evening, and another small glow hole in the floor at (7). East of the main western pool a rocky slope led down to (5).

September 21, in the morning and early evening, vapor was diffused through the pit obscuring the view. At 7:30 p.m. the bottom showed conditions similar to the previous night, but lava spurted from two holes of about equal size at the eastern blow-hole locality.

On September 22, at 5 p.m., the first clear view for many weeks of the bottom by daylight was obtained. It confirmed the survey, in that the W lake was on a shelf above the eastern floor containing the blow hole, and the S glow hole was in the talus at a level between the two floors. The blow hole was less noisy and emitting more flame and gas than lava. A slope of rocks marks the descent from the W pool to the eastern floor. The S hole was lined with stalactites, and near it was a spatter cone shaped like a bee hive, whitish, and showing glow within and flames through crevices in its crust. This cone was the flaming fissure of (5) noticed September 20.

A glimpse on the evening of September 23 about 6 p.m. showed three holes at the blow-hole locality, and these appeared to have built up a low dome. The puffing noise was not strong. At 3 p.m., September 24, no changes were observed. September 25, in the evening, the fumes were heavy, and the glow over Halemaumau was dull.

The Observatory was honored by a visit from the Secretary of the Interior and Mrs. Fisher and from Governor Frear on September 22.

Relative humidity records have been added to the meteorological observations. The weather of late has been uniform, with temperature ranging between 50° and 70° F., humidity high, clear mornings and rainy afternoons.

September 19, a series of photographs, one to be taken each day from the concrete pier in front of the Observatory, was started. The photograph is taken about 10 a.m., and the camera is pointed directly at Halemaumau so as to show the crater, the fume cloud, and the distant Pahala district on the slope of Mauna Loa. The object of such a collection is to record (1) character of day, (2) cloud effects, (3) changes in the vapor cloud, (4) small vapor jets on crater floor for comparison with record of relative humidity, and (5) possible changes in shape or height of the rim of Halemaumau (Pl. 8).

September 24, the minor Omori tromometer was taken to the Technology Station at Halemaumau to be set up for comparative records of seismometric movement at the pit edge. However, the shell lava on which the station is placed is too unstable for seismometric work, and the fumes greatly damaged the instrument, so that it had to be removed.

A reconnaissance of the S side of the pit September 23 revealed much accumulated "Pele's hair" or filamentous lava. The southern interior slopes of the pit show tumbled benches and sulphurous fumaroles smelling of pure spicy sulphur. The cable used for rescue in January 1912 along the W border of the high embayment of 1894 on the W side of Halemaumau has completely decomposed, showing maximum attack of acid vapor at that place.

WEEK ENDING OCT. 3, 1912

The nearly stationary condition of the lava of Kilauea, with some increased activity, continues. During the past week there has been hardly any change, until the evening of October 2, when there was a marked increase in glow, noise, and possibly in height (Fig. 4). There has been some building up of spatter cones on the bottom, and as the lava is working in pits in their summits and overflowing therefrom its level is probably a few feet higher. The general topography of the bottom has not changed, and there have been no rock slides. Two phenomena of the present phase of activity are of interest—the blowing cone, and the maintenance of three pools in the bottom area at different levels. The blow hole mentioned in recent reports has formed a low cone, and its noisy mechanism appears to reproduce the famous blowing cones of the first third of the nineteenth century, which the early missionaries counted by scores on the floor of Kilauea. The greater height of the western pools above the blow hole and the southern pits, while lava boils and maintains different levels at each place, illustrates locally the fact, often noted before in Hawaii, that adjacent bodies of fluid lava do not show hydrostatic equilibrium but are maintained independently by internal gas pressure or some such agency.

September 26, at 10:25 a.m., there was no seeing, the fumes were diffuse and white but not very heavy, continuous puffing could be heard, but there were no loud puffs from the blow hole. One hundred feet under the southern remnant of the January bench thin dusty brown fumes were rising from the talus under the edge of the fallen bench block. About 100 feet lower, from under the edge of the down-tilted bench of July 1912, thick purling pure white vapor arose. The surface of the July 200-foot bench SW below the southwestern sulphur patch was still preserved in part with a greatly cracked upper surface inclined toward the center of the pit like a single great broken slab. In the evening there was increased activity and a small boiling pool at the blow hole locality, which made a brilliant flaring display on the clouds of vapor above. On September 27 there was less glow.

September 28, dim views were obtained in the evening from the SE; the blow-hole fissure was shaped like a cross and splashing with fluid lava, and lava surges appeared in the S hole. In the W end three or four small glow spots showed dimly in a line. Nothing was seen September 29. The flaming glow was less.

September 30, strong gurgling and blowing sounds could be heard, there were no avalanches, and the fumes remained impenetrable. The glow in the evening was dull with occasional flaring. October 1, the glow at night was very dim, and the fumes were heavy.

October 2, from 7:30 p.m. until 10 p.m., light northerly winds opened the fume veil and exhibited the bottom area to spectators at the SE station. The fumes appeared thin, and the activity of the lava was strong. The western pool was completely outlined by glowing cracks and showed three bright fountains surging through holes in the crust. Its form as a whole was as on September 20, when it was last seen in its entirety. North of it and higher up the cliff a large chimney emitted a wavy blue flame. Two pits containing lava, which sometimes overflowed, appeared on the S side of the bottom area and lower than the large W pool. At a still lower level E, a large lava floor—the 593-foot level of September 20—contains the blow hole (probably equivalent to Old Faithful) and numerous cracks and flaming holes. This floor appears to be a flat cone with the blow hole for its apex. At 9 p.m. this floor split in several directions, fluid lava welled up through the cracks and overflowed the whole eastern area as far as the larger of the southern pits, while the blow hole continued to blow tremendous puffs of gas with much noise. The lava flood cooled and blackened, and the several glowing holes continued as before. The blow hole was V-shaped and was spouting almost horizontally to the east, rarely ejecting fluid but making rocketlike noises.

Two local earthquakes have been registered during the past week. One, September 20 about 5:06 a.m., was not felt at the Volcano House and did not start the ordinary seismograph. Even on the record of the major tromometer its motion is registered feebly though distinctly. Nevertheless this shock was felt at Hilo and was considered fairly strong there. The vibrations of the first phase measured on the seismogram, enduring from 2 to 3 seconds before the arrival of the stronger motion, indicate that the origin is approximately 20 miles from this station. For shocks originating so near the place of observation our formulas for determining distance are not very accurate.

The second local earthquake, in the night of September 30–October 1, was not felt at the Volcano House though it started the ordinary seismograph. Unfortunately the time of its occurrence was lost because of an accident to the major tromometer.

Besides these local shocks there was registered in the forenoon of September 29 a strong teleseismic disturbance, a shock of the world-shaking order, which is the first distant earthquake recorded at this station. Its chief phase was registered as a simple wave motion of large amplitude (probably exaggerated through resonance) with a subsidiary group of large waves 2 or 3 minutes after the subsidence of the chief group. Some waves of the early phases were very distinctly registered with considerable amplitude, but the motion of the first and second phases is not registered continuously, and the "tail" or dying-out phase ceases long before the earth motion had, in all probability, died away. This emphasizes the fact that friction is present in some part of the mechanism, due to a defect in manufacture. Owing to this friction the time of the beginning of motion is uncertain. Consequently the distance of the origin from the station cannot be determined accurately though it is no less than 5000 miles from Hawaii. The shock was an earthquake of great power. It began not later than 10:45 a.m., H.S.T. (September 29); its chief motion began shortly after 11:00 a.m. and remained strong for about 15 minutes, and there was sure registration of motion for more than an hour. The motion of the "tail" phase should have endured much longer.

WEEK ENDING OCT. 10, 1912

The volcano continues to emit white fumes copiously, though the amount is much less than a month ago, but clear views of the lower part of the pit are rare. As seen from the Observatory at night the amount and intensity of the glow has been variable from hour to hour, with occasional bright flaring due no doubt to sporadic outflows of molten lava in small quantities on the present solidified surface of the lava lake. The appearance of the solidified surface of the lake has not changed much from that described in recent reports—1 or 2 orifices with about 12 to 15 glowing spots dotting a thick black crust. Nevertheless the surface has risen; the amount of overflow observed seems too small to account for all the rise. The depression to the molten lava in Old Faithful was

October 9, 9 p.m., below E station.. 475 feet.

On October 3 and 4 the fumes appeared to have little volume, though on the former day the humidity was 94 per cent. The evening glow was fairly bright on October 3 but dim on October 4. On October 5 the fumes appeared to increase in volume, but the evening glow was bright, with flaring.

October 6, at 5 p.m., the pit was obscured by fumes. There was continuous blowing noise, with occasional noisy puffs from Old Faithful. The high sulphur-stained vent on the S talus emitted small, thick, white jets of fume, whereas recently it has been wholly free from fumes. After 6 p.m., with the twilight, a change in wind from E to N opened the SE amphitheater and exhibited a remarkable spectacle in the bottom area. The large raised pool at the W was represented by only three or four small spitting pits with lava within. The two southern vents at a lower level appeared as a single fountain of very liquid lava apparently on the apex of a cone, with a stream 30 feet wide flowing from it to the E, rapidly above, and forking, widening, and festooning below, progressively more crusted over from top to bottom. The fountain welled up like an artesian flow without any sputter or exploding and quite continuously, 10 or 15 feet high, shaped like a dome. Finally another fountain broke out S of it and close to it in the same cone and developed into its twin with only a narrow partition. From this second fountain a lava flow sped southward to meet the first flow. The Old Faithful vent farther NE was exploding at intervals with a great lava splash about its rampart, the pool appearing to be 50 feet across and to send its spray fully as high. It overflowed to the eastward occasionally. Eventually, about 6:45 p.m., the flow from the S vents so filled the area about them with blackened lava that the two dome-shaped fountains were left within circular holes in a crust around them, still boiling with continuity, but more spasmodically than when their flow was free and over the slope. Meanwhile the area between Old Faithful and the western pool appeared outlined with a glowing zigzag line as though half-crusted flows or pools of lava were filling the intervening space. The whole process, flow S and E at the lower places, stagnation W at the higher, suggested a breaking through the partition between them and a tendency to adjustment of level eventually to unite the areas in a single pool. The greater activity and the building indicated by the fountains, coupled with increase of glow at night, implies a rise in the lava column.

In the evening of October 9 the fumes were much thinner than since the first days of August, permitting measurements for depths. The Old Faithful orifice was open, and from it were ejected considerable masses of lava at short irregular intervals. Spatter fragments fell noisily on the solid crust about it. No flow was observed. A second small orifice S of Old Faithful and on the S margin of the lake also ejected spatter fragments at longer intervals. A constant emission of gas was accompanied by harsh sounds like stifled breathing. No changes were observed between 8 and 9:30 p.m.

WEEK ENDING OCT. 17, 1912

Conditions at the pit of Halemaumau have undergone little change. The fumes, though growing thinner, are still sufficient to veil all the lower part of the pit except at rare intervals. In the night an occasional good view can be obtained. Of late all surveying has been conducted at night and is subject to errors of reading due to trying conditions of light, and uncertain settings. Last week, on the basis of an earlier triangulation made at night, measured depression angles gave the depth of the Old Faithful orifice in the frozen floor over the lava lake as 475 feet below the eastern rim. During the present week a retriangulation has been made by day fixing the relative datum positions of the N, NE, E, and SE rim stations. As a result, the former location of the SE station was slightly in error as the triangulation had been made by night, using a bright light signal. During the day the heavy outflow of fumes had interfered with sights between stations. This error affects the earlier depth measure of 475 feet, reducing this value by an unknown amount. On the evening of October 16 the depth of the Old Faithful orifice was measured as 363 feet. This measure was made on the basis of the revised base lines, was checked, and is reliable.

There has been a rise of the summit of the lava column. Flows have been pouring from minute orifices in the congealed floor over the lake, building up its surface. Whether any upfloating of the crust accompanied this action is unknown. Hence the measure of a week ago, 475 feet, though probably too great, represents a truly greater depth than the present reliable depth measure of 363 feet. Comparison of the two sets of depth angles, which are not affected by any fault in triangulation, confirms this and indicates that the rise of the past week has been only slight, but owing to changes in the Old Faithful orifice an exact evaluation of the error is impossible.

The appearance of the lower part of the pit remains unchanged except in details. The solidified surface of the lake is a rugged, uneven floor with numerous very small orifices in it through which the lava glows at night. Two or three larger ones are very irregular. One is Old Faithful which continues to eject rockets or fountains of lava at irregular intervals, producing at night a bright flaring illumination of the swirling fumes. The escape of gas produces a continuous harsh, strong rhythmic hissing, like the escape of steam from an exhaust valve.

On October 12, the evening glow was strong, with brilliant flaring. Visitors report flows cascading from W to E from the higher part of the floor to the lower.

On October 13, a flow from the higher western levels poured into the Old Faithful orifice, whence, simultaneously, masses of lava were spurted out spasmodically at intervals.

At other times during the week the evening glow has been faint, and the known activity has been confined to the sporadic jets from Old Faithful. Observation at the pit side by day is unsatisfactory.

Seismically the week was one of marked activity, though most of the earthquakes would have escaped notice except through registration by seismograph. With the receipt, on October 10, of a rated chronometer from the office of the Territorial Surveyor, loaned by the College of Hawaii, the writer is able to give the times, to the second, of occurrence of these shocks, in Hawaiian Standard Time, but with the reservation that, as the rate of the chronometer is subject to change with temperature, the values given are not checked sufficiently for seismometric correlations.

A very feeble shock, not felt, was registered beginning at 9:27:36 p.m., H.S.T., on October 11. The distance of its origin could not be estimated accurately, but the focus was very near, possibly within the active cistern of the volcano. It may have been no more than a strong group of the continually occurring "volcanic tremors", which are really earthquake motion of unusually feeble energy and of uncommon duration, a practically unending series of rapid, feeble impulses differing from the stronger impulses in genesis, strength, and interval only. As recorded seismographically the motion lasted for about 45 seconds.

On October 12 from about 5:07 a.m. to 5:22 a.m., H.S.T., feeble, irregular waves of moderate period were registered, interfered with by friction in the seismograph. This motion was probably the feeble expression of the chief phase of a distant shock. If so the origin was at a moderate, rather than a great, distance.

On October 12 a very feeble, local shock was registered beginning at 10:30:38 a.m., H.S.T. It was feeble and did not show distance of origin.

Early in the morning of October 13 an earthquake was distinctly felt at the Volcano House. The motion communicated to the second story of the hotel was gentle and relatively slow, yet sufficient to waken light sleepers. This was a multiple shock, eight distinct maxima being counted by Mr. L. A. Thurston at the Volcano House. It is doubtful if this could be due to a peculiar response in the swaying of the structure. Owing to stopping of the driving clock of the major tromometer, this shock was not registered properly, and neither the time nor duration was measurable. The maximum motion indicates that it was of only moderate strength. It occurred about 5:45 a.m. This shock was felt lightly in Honolulu and distinctly in Hilo. The writer concludes, since the area of sensible motion was fairly large and the motion nowhere strong on land, that this was a submarine shock, of fairly deep origin and relatively slight energy.

Throughout the forenoon of October 13, the pendulum of the major tromometer swung irregularly with long period indicating rapid and irregular movements of tilting at the edge of the Kilauea sink. These movements were superposed upon the normal diurnal tilting.

A distinctly registered shock, too weak to be felt, was registered at 4:03:54 p.m., H.S.T., on October 13. Vibration was measurable for 1 minute and 7 seconds.

A very weak shock was registered for 1 minute and 3 seconds beginning at 6:48:46 a.m., H.S.T., on October 14.

A swarm of eight earthquakes in rapid succession occurred as follows:

October 14, 11:38:53 p.m. H.S.T....	a very feeble shock
15, 1:20:33 a.m..........	very feeble but definitely a shock
15, 1:33:17 a.m..........	a well-marked shock but feeble
15, 4:42:00 a.m..........	fairly strong but not reported as felt, started the ordinary seismograph

15, 5:06:34 a.m.	very feeble, possibly a group of volcanic tremors
15, 6:02:52 a.m.	feeble but definitely a shock
15, 6:34:39 a.m.	very feeble, possibly volcanic tremors
15, 7:08:04 a.m.	very feeble, possibly volcanic tremors

These shocks were all local, and two of them approached or reached an intensity great enough to be felt though none have been reported. Their place of origin cannot be estimated.

Seismometric Standards:

On September 24 a small two-component horizontal-pendulum seismograph such as was used for meteorological stations in Japan was set up in the hut on the N side of Halemaumau. It did not prove very useful, as its magnification was too low, and its mechanism was damaged by the acid fumes. The formula used for determining distance of origin from station of local earthquakes was based on the Zeissig table referred to by Galitzin (1914). Ten years later the Omori (1918) formulae for local earthquakes were used, based on the travel times of the preliminary and secondary waves as determined in Japan. About 1932, the seismologist of the Observatory (Jones, 1935b) made some determinations of the actual travel times of the different phases of earthquakes in the rocks of the island Hawaii, and these formulae are believed on the basis of experience to correspond more closely with the facts in locating earthquake origins. Intensity of earthquakes was expressed by Mr. Wood in fractions or multiples of the "minimum perceptible unit". The correlation of measured acceleration from the seismogram with reports of earthquakes actually felt did not check with the expectation of perceptibility in the several well-known scales of earthquake intensity (Wood, 1914). Wood concluded that amplitude of the motion in weak earthquakes of very quick period plays an important part in making an earthquake perceptible, when the acceleration value becomes high by reason of the quick period. In other words a very quick period vibration of small amplitude may have a high acceleration mathematically and yet be imperceptible. Hence for ordinary local earthquakes of periods from 0.2 to 0.5 seconds, the "feeling" of the quake as a measure of intensity is probably dependent on the amplitude.

WEEK ENDING OCT. 24, 1912

For the past week there has been little activity. In all essentials the volcano remains as described in recent reports, veiled by day, except for rare momentary glimpses. By night short occasional views disclose no noticeable changes. Much rain in the evening has resulted in less observation than usual. During the past 7 days the depth has not been measured.

Illumination of the fumes by night has been feeble, though on October 19 and October 20 there were intervals in the late evening during which the illumination was strong with occasional bright flaring.

In the early morning of October 23 there was also relatively strong illumination. Of late all such spasmodic periods of strong illumination, when observed at close range, have been due to small flows pouring out over the frozen surface of the lake from one or more of the numerous tiny openings in the crust. Presumably the illuminations observed during this past week have been caused in this way, also, although none have occurred when observers were at the pit. Hence the slow rise of the lava column is presumably continuing. The wheezing and hissing noises due to gas escaping through blow holes continue.

Several earthquakes have been registered during the past week, though all have been very, very feeble, except one. Most of the shocks are so feeble that an attentive observer could not possibly perceive them.

Between 5 and 8 a.m. on October 17 a very feeble shock was registered. Confused and intertwined overscoring of the lines of the seismogram makes its time of occurrence and its dimensions rather vague.

On October 18, beginning at about 1:43 a.m., there was registered for a few minutes an irregular wave motion which merges with the ever-present microseismic waves. It may be the chief phase of a teleseismic disturbance of moderate energy originating at moderate distance. No serviceable measurements of it could be made.

On October 18, a feeble local shock, originating about 30 miles away, began at 12:10:52 p.m. and ended at 12:12:40 p.m., H.S.T. This manifested an intensity a little more than $\frac{1}{20}$ that of the minimum shock perceptible to the senses.

On October 20, from 10:49:21 a.m. to 10:50:07 a.m., H.S.T., there was registered a feeble local shock with an intensity of about $\frac{1}{40}$ that of the minimum sensible shock. A shock also occurred beginning at 1:57:52 p.m. and ending at 1:58:44 p.m., H.S.T. This originated about 25 miles from this station; it was a definite earthquake, not a group of volcanic tremors, yet its intensity was less than $\frac{1}{100}$ that of the minimum perceptible. Another, still more feeble, a definite earthquake, originating at like distance, began at 4:32:59 p.m. and ended at 4:33:53 p.m., H.S.T.

On October 21, a disturbance, possibly a group of volcanic tremors was registered from 8:26:23.5 a.m. to 8:27:07 a.m., H.S.T. Its intensity was about $\frac{1}{80}$ that of the minimum perceptible. Another very small was registered from 3:41:31 to 3:41:50 p.m., H.S.T.

On October 22, a disturbance of ambiguous character was registered from 11:15:22 a.m. to 11:16:29 a.m., H.S.T. Its intensity was about $\frac{1}{60}$ that of the minimum perceptible.

A very feeble local shock was registered on October 23 from 4:52:43 a.m. to 4:53:15 a.m., H.S.T. It originated 18–19 miles away. Its intensity was about $\frac{1}{50}$ that of the minimum sensible shock.

A shock of greater energy occurred on October 24 after 00:50 a.m., H.S.T. It started the ordinary seismograph but was too weak to write a distinguishable record. The driving clock of the major tromometer again stopped, for no discernible reason, so that no record of the time, distance of origin, nor the intensity was obtained.

Week Ending Oct. 31, 1912

As an object of study, Halemaumau is still far from satisfactory. Only rarely a glimpse is to be had by day. Nevertheless, conditions have been improving. The exhalation of fumes has gradually diminished until now at night brief glimpses of the surface of the lava lake are frequent. The level seems to be oscillating, for frequently during the past week there have been times of brilliant illumination due to the extrusion of small flows out upon the solidified crust of the lake, suggesting a slow process of upbuilding, yet a measure on the evening of October 29 gave depth

Oct. 29, 8 p.m., below E rim,.. 375 feet,

a depth about 12 feet greater than that found by the last measurement (363 feet, October 16). Throughout the week the times of brilliant illumination at night have been more frequent, and the brightness greater, than in the weeks immediately preceding, though there have been considerable intervals of dullness when there were no flows and the open orifices were not active.

On the afternoon of October 28, a brief glimpse revealed a conspicuous spatter cone within the area of the frozen lake near its S margin and near its W end. Very loud hissing and blowing sounds proceeded from this, sounds comparable to the noise made by several large locomotives blowing off steam.

On the evening of October 29, the lake was much as hitherto described, a black crust with two or three larger and a considerable number of smaller orifices, but the crust was thinner than in recent weeks, and, at the W end, seen dimly in glimpses through the smoke, there was an area where the crust occasionally broke up, flowed about, and sank, followed by the freezing over of the area with the formation of a fresh, thin crust—in other words, a small active lava pool.

On the evening of October 30, there was similar action at the E end of the lake—a slightly larger region in which the crust cracked, moved about, and sank, accompanied by small, thin outflows from this disturbed region over the neighboring surface of the lake. This activity was the most marked since the middle of August.

Meanwhile the chief orifices continue at intervals to discharge small jets of molten lava to considerable heights. The Old Faithful orifice, though choked, is the most active, at night flaring at short irregular intervals.

On the whole all the recently observed behavior points to an increase in the energy of eruption with increase of heat at the surface of the lava column, but without any definite net rise of the column during the last fortnight.

Several feeble earthquake shocks have been registered this week. It is difficult to distinguish between true earthquakes and volcanic tremors, when the energy is no greater than in these cases.

On October 25, a shock began at 11:42:59 a.m. and ended at 11:43:19 a.m., H.S.T. This originated about 12 miles away. Its energy was about $\frac{1}{150}$ that required to render it perceptible.

Between 7:30 a.m. and 9:15 a.m. on October 26, there occurred three shocks, all of about the same energy, about equivalent to that of the shock just described. The exact times of these are lost owing to the stopping of the station time clock.

On October 27, a light shock, of intensity about $\frac{1}{38}$ the minimum perceptible value, was registered for 1 minute beginning at 6:32:35 p.m., H.S.T.

On October 28, a shock of $\frac{1}{30}$ the minimum perceptible intensity was registered from 4:53:17 a.m. to 4:54:23 a.m., H.S.T. The origin is estimated to be 31 miles away.

In the last few days conspicuous microseismic waves have been registered continuously, and there has been active tilting of the surface here.

Winter Rise of Lava:

Already in this first year of the Observatory, the expectancy of rising lava in December–January was known, and this was based on such remarkable risings with intense ebullition as had occurred in December of 1909 and 1911. During a number of years in the next decade this rising in winter was verified. It accompanied a systematic annual culmination in the phenomena of tilting of the ground at the Observatory on the NE edge of Kilauea Crater (Jaggar and Finch, 1929). The tilt to the NE, away from Halemaumau, began in midsummer, culminated in midwinter, and was followed by tilts to the SW in the spring. The marked rise of lava in the autumn made a characteristic upward curve in the plat of lava movement for every year between 1909 and 1923, except in 1913 when the lava was too low and smoky to be measured. Even in that year there was indication of an autumnal rising. This annual movement of combined crateral tumescence and lava gushing, participated in by the entire Kilauea-Mauna Loa system in 1914, 1915, 1916, and 1919, when Mauna Loa asserted itself, could not be attributed to meteorological controls like rainfall, which in Hawaii are highly localized. The phenomena are too deep-seated to be easily attributed to the slight changes of atmospheric temperature and barometric pressure. There remains the probability of a solar effect on the crustal tide, in some way affecting magma, with a trigger mechanism by either gravity or magnetism.

WEEK ENDING NOV. 7, 1912

With slight fluctuations in level and increasing activity, the lava pit has during the past week become a brilliant spectacle. The marked rise since September, the large crusted pool, and the number of active boiling pots and ponds within the crust area suggest the beginning of the winter rise which is expectable on the basis of experience.

The levels of the lake have been as follows:

		Feet
Nov. 1, 9 p.m.,	western oven-shaped hole, below E and SE stations	370
	S pool, below E station	376
	Old Faithful blow hole, below E station	369
4, 7 p.m.,	large W pool, below E station (Fig. 4)	390
	Old Faithful cone much higher than pools	
	W chimney 50 feet higher than the W pool	
7, 10 a.m.,	large W pool, below N and NW station	377

On November 1 Mr. Wood reported good views of the lake from 8 to 9:45 p.m. There was a large crusted pool with numerous orifices that revealed boiling magma. Old Faithful in the N middle part was a choked triangular hole in solid crust, about 10 feet long. It exhibited greater activity than recently, vomiting powerful lava jets over 100 feet into the air at intervals and showing in the meantime a conspicuous blue flame which fluttered over the orifice, 20 or 30 feet high.

At the western end an oven glowed quietly. Most of the lava ponds lay on the N side of the lake. Eight of these were between Old Faithful and the W oven, continuously boiling and sometimes fountaining 20 to 30 feet high. There were four pools in the eastern part of the lake. One SE of Old Faithful, 40 or 50 feet long, had a boiling cave under its N bank toward which the crust streamed as it was torn from the margin. A still larger elliptical pond S of this kept freezing and thawing with inward flow and foundering of crust blocks. At the extreme SE angle of the lake a smaller cave filled with lava in ebullition was fed from an area of torn and flowing crust. There was another freezing and thawing pool at the E margin, and the entire E and S part of the lake area was traversed by cracks where at times there was thawing with streaming flow. The lake was larger than at this season last year, and the thinness of the fumes and intensity of activity were more pronounced than anything seen at the crater since early in August.

November 2 from 5 p.m., the first daylight glimpse of the lake for many weeks was obtained by Mr. Wood. From 5:30 until 7 p.m. there were some intervals of clear view, and the south pool and Old Faithful were active, the latter choked to a very small orifice. The SE and NE pools were sluggish, but those at the W end were larger than the night before. The glow was so strong that some night photographs were obtained.

November 3 at 8:15 p.m., the pools looked about the same. Streaming currents flowed out from the S shore of the lake, and two opposed currents flowed toward each other in the large western pool with a stagnant skin between them. There was a high glowing chimney in the wall at the W end of the lake, and though the fumes were obstructive the pools could be seen from the old rest house on the N cliff (Fig. 4).

From 6:30 to 9 p.m. November 4, a survey of the lake was made. The outline is similar to that of the lake of February 1912 (Report Hawn. Volc. Obs'y. Jan.–Mar. 1912, Fig. 29, p. 59–68) the coves being E, NE, N, NW, and S. The lake was 460 feet long E–W, 350 feet wide N–S, and the open W pool was 115 feet long N–S by 35 feet wide. The largest areas of fluid lava are at the W end. On this date there were overflows through a rampart NE. The Old Faithful crack, at the summit of a flat cone built up above the mean level of the lake, was ejecting great spurts of lava which fell back on the hard surface half congealed, with thudding noises. South of Old Faithful a straight crack in the crust at least 200 feet in length trends W–NW parallel with the lake's longer axis. The measurements of mean level indicated a fall of 15 to 20 feet during the preceding 3 days. Blue flames played through cracks in the crust.

From November 4 to November 6 there was increasing activity—slow rising and diminishing fumes. On November 6 in the morning heavy falls of spatter could be heard from the Old Faithful cone, and occasional glimpses of the lake through the fumes revealed breaking angular crusts over the lava which tended to founder.

On November 7, for the first time since early August, photographs of the lava pools were made by daylight without serious interference by the fumes. Old Faithful was blowing with a great noise at intervals, and there was strong surface flow from the S side of the lake. A small flow poured down the W side of the Old Faithful cone. The main sources of fumes were from lines of wall vents W and N, the western ones yellow with fresh sulphur. There was a large pool at the W end of the lake area, a chimney in the W wall, and conspicuous cracking in the 200-foot bench on the S side of the pit.

The Director returned from Honolulu to the Observatory November 3. While in Honolulu through the month of October he succeeded in increasing the membership in the Volcano Research Association and completed the First Quarterly Report of the Observatory.

The following is Mr. H. O. Wood's report on the seismograph records of the week at the Whitney Laboratory of Seismology; among them is a seismogram of a distant earthquake of great magnitude, which registered at this station between 9 and 10 p.m. on November 6:

During the week three very slight local earthquakes have been recorded.

One registered from 10:46:27 p.m. to 10:47:46 p.m., H.S.T., on October 31 reached an intensity of about $\frac{1}{19}$ the minimum sensible shock. The distance of its origin could not be estimated.

A shock registered on November 1 from 10:28:14 a.m. to 10:28:40 a.m., H.S.T., originated approximately 26 miles away. This reached an intensity of about $\frac{1}{40}$ the minimum perceptible to the senses.

A shock registered on November 1 from 11:30:48 a.m. to 11:31:11 a.m., H.S.T., also originated about 26 miles away. This attained an intensity of about $\frac{1}{35}$ the sensible minimum.

In the evening of November 6 a strong world-shaking earthquake was recorded. The first waves began at 9:18:10 p.m., H.S.T., followed after 5 m. 47s. by those of the second phase. The strongly registered surface waves arrived sharply at 9:26:43 p.m. After two or three swings the motion became so strong that it exceeded the range of the seismograph, sweeping the writing index off the recording drum. It returned after 2½ minutes. Owing to excessive friction the registration probably ceased long before the motion died out, but it continued for more than an hour.

The distance of the origin of this shock was approximately 2450 miles. Its direction cannot be determined by the equipment of this station. The distance in this instance is ambiguous, it being approximately 2500 miles to the region of southern California, to the central part of the Aleutian chain—both regions in the circum-Pacific seismic belt—, also to the Society Islands, the Samoan group, and the Gilbert Islands, any of these regions being liable to the occurrence of strong shocks.

Old Faithful Fountain:

The measurements of intervals between the outbursts of Old Faithful fountain (Report of the Hawn. Volc. Obs'y., table showing intervals of Old Faithful, January–March 1912, p. 72), here reported as changing from a blow hole to a fountain, may be briefly explained. Old Faithful was well known as a periodic fountain in Halemaumau, with intervals of 20 to 40 seconds, and notably irregular. It seemed regular to casual observers. During the year of first systematic observation, 1912–1913, when the pit bottom developed two funnels E and W, the western pool developed a second rhythmic fountain called "New Faithful". In later years some of the fountains became almost continuous jets breaking through the crust out in the central region of the lakes. Some of the fountains are against the lake shore and build up a half dome on the bank hung with stalactites; these are called "grottoes". It became evident that the Old Faithful type of fountain is over a sink hole of the convectional circulation. The gas-charged slag, cascading down a well, agglomerates vesicles into large bubbles which escape through the skin of the lake at intervals, dependent upon the rate of such accumulation. The wells are in cooler semicongealed lava, later referred to as epimagma (Jaggar, 1920).

Week Ending Nov. 14, 1912

Kilauea continues its activity, with fumes on the whole becoming thinner, occasional good visibility by day, and fine spectacles every night. The fume cloud, however, was dense until November 12. The level of the lava in Halemaumau has not changed essentially during the week from November 8 to 14. The activity and shape of the boiling and streaming pools have changed greatly day by day, the total effect being to merge scattered ponds and to reveal finally the fountain Old Faithful, so long concealed under a blow hole in hard rock. This last change, which engulfed the blowing cone and revealed a pool of melt beneath, took place between November 12 and 13.

The last measure of depth of surface of the W pool below the edge of Halemaumau pit, reported last week for November 7, was 377 feet. At 4 p.m. November 11, the fumes were dense, a new high glow hole showed SE, and an occasional strong puff could be heard from Old Faithful.

A fairly complete plane-table survey of the bottom area was made between noon and 5 p.m. November 12 from two stations on the S and SW rim. Two oval pools in ramparts of their own building occupied the SE and NW parts of the area, separated by a ridge, with the spatter cone of Old Faithful between them and a little to the northward. A new and powerful fumarole was seen in the talus 257 feet beneath the SE station. There were noises of fountaining and rare puffing sounds.

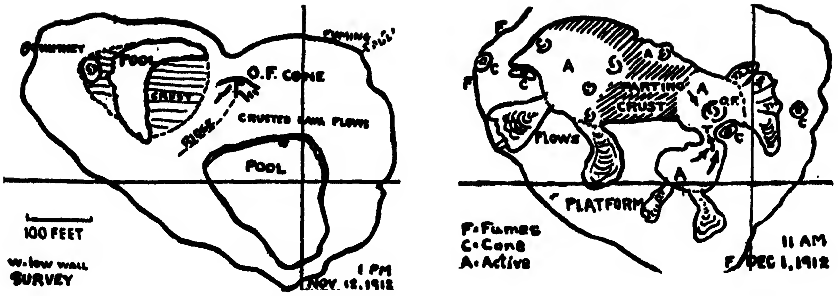
The following levels were determined November 12, beneath the SW station (Fig. 5):

	Feet
West pool, average depth of pit to surface of pool	377
East pool, " " " " " " " "	372
Average depth to pools beneath edge	374
Depth to summit "Old Faithful" cone	360
Depth to border of lava flows outside of pools	372

The plan made by this survey shows the active part of the W pool crescent-shaped with the horns pointed E, a smaller active hole farther W, and still farther W a chimney high in the bank. The Old Faithful cone was an irregular rocky bee hive with a glowing hole in the E side of its summit which occasionally ejected lava spray rather weakly. The rampart about the eastern pool was 4 or 5 feet high, and from it, as from old Faithful and the western pool, chilled lava flows sloped away gently to an irregular elliptical outline bounding the whole area of new lava, within the pit wall and slide rock. The eastern pool had active boiling pots E and W, and the rest of its surface was a cracking crust with liquid oozing up the cracks. Blocks occasionally cracked and foundered in the W pool also (Fig. 5).

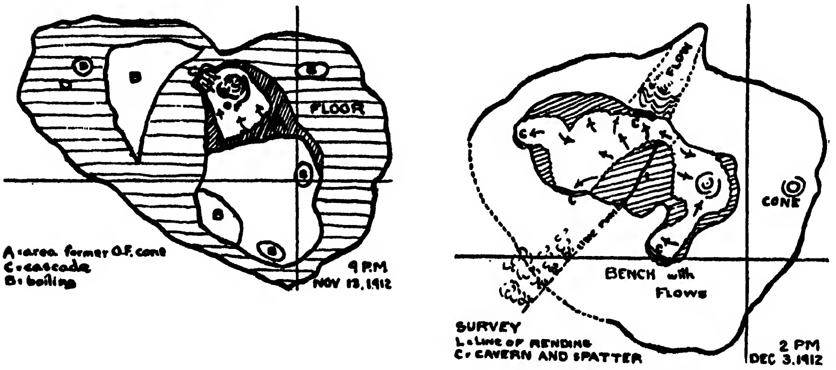
On November 13, between 8 and 10 p.m., an extraordinary transformation (Fig. 5) had taken place. Conditions at the W were about the same, but the Old Faithful cone and a field of lava E of it had collapsed so as to double in size the southeastern pool and extend it over the whole E floor. For the first time in some weeks Old Faithful was its normal self, fountaining rhythmically every 30 to 40 seconds within a pool of partly crusted lava and, near the NW border of the eastern pool, throwing its spray over the remnant of its bee hive on the shore of the isthmus between the eastern and western pools.

The most remarkable feature of Old Faithful, however, was a cataract of liquid glowing lava which poured from a hole in the bank W of it and right into the swirling, seething caldron of the fountain. This hole appeared to be a cavern about 5 feet wide, horizontal, and penetrating the rocky isthmus which separated the western pool from the eastern. It was only a few feet above the Old Faithful pool, for that fountain deluged the cataract with its splash. The cataract poured out under pressure, like water from a garden hose, and now and then the roof of its tube extended flapping black skins



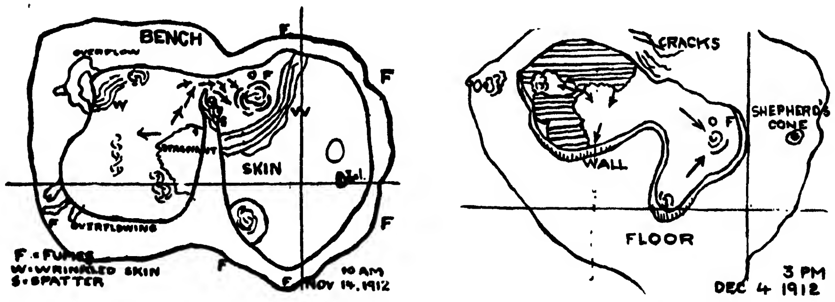
a. November 12; recovery of two pools. Old Faithful a cone.

d. December 1; crusted lake with overflows.



b. November 13; recovery to three pools.

e. December 3; lake with bench and inward flow.



c. November 14; west pool source, east pool a sink-hole.

f. December 4; double lake and floor cone.

FIGURE 5.—*Lava lake maps November–December 1912*

(*See* Figure 1.)

or curtains over the flowing glass, which skins eventually tore off and were carried down on the surface of the cascade into the pool beneath. The effect suggested ordinary hydrostatic pressure, as though the lava from the western pool were pouring through this hole into the eastern pool. There was some suggestion, at the tip of the N horn of the crescent-shaped western pool, of inflow under the bank opposite the place of emergence of the cascade, but surface skins masked what was going on beneath. The W pool was boiling, and a small western pot was separated from the rest by crust. The E pool contained four boiling ponds, other than the one around Old Faithful, and cracking and foundering was in progress to the NE. Old Faithful sometimes burst into triple or quadruple fountains. The streaming in the E pool other than that occasioned by the cascade into Old Faithful was from the S. A high glow hole showed above the pool to the NE.

That drainage from the W pool to the E was actually taking place was confirmed November 14, when the whole pool was splendidly revealed between 9 and 10 a.m. and visible from the NW station. The roof of the tube had collapsed, just as the Old Faithful cone had, and there was now a river of molten lava, 15 or 20 feet wide, pouring around the N end of a peninsula where the isthmus and the tube were yesterday, from the W pool into the E pool; the stream poured directly into the Old Faithful fountain. The two pools had thereby merged into one, shaped like a pair of well-stuffed saddle bags, with the river the connecting strap. The peninsula had the remnant of the Old Faithful cone at its northern end, and this was being enlarged by spatter from the adjacent fountains.

Recent overflowing on the floor to the N and W was still in progress on the W. A small islet stood in the southeastern part of the E pool surrounded by quiet cracked skins. Fumes rose from the rim of the floor on the E, NE, SW, and S (Fig. 5).

In the evening, November 14, rising was so rapid that the peninsula dividing the two pools was submerged beneath the lava so that only one large lake appeared.

Mr. Wood reports four slight earthquakes recorded on the seismograph during the past week, as follows:

Nov. 7, from 2:15:43 p.m. to 2:16:29 p.m., H.S.T.
8, from 3:01:36.5 a.m. to 3:02:47 a.m., H.S.T.
9, from 4:14:23.5 p.m. to 4:15:32 p.m., H.S.T.
12, from 8:57:00 p.m. to 8:57:47 p.m., H.S.T.

All have been local with the origins distant from this station approximately as follows: Nov. 7, 28 miles; Nov. 8, 15 miles; Nov. 9, 14 miles, and Nov. 12, 18.5 miles.

Taking the minimum intensity perceptible to the senses as unity, the approximate value of the intensities of these in order have been $\frac{1}{35}$, $\frac{1}{22}$, $\frac{1}{17}$, and $\frac{1}{120}$, respectively.

WEEK ENDING NOV. 21, 1912

At Kilauea, although the white fumes continue to diminish in volume, they are still sufficiently thick to veil the pool by day when hard winds are blowing, and for several days past the northeast winds have been strong and gusty. Rain, especially at night, has also interfered with useful observation.

During the latter part of last week the upper part of the Kilauea lava column, its top visible in Halemaumau, was changing rapidly. This continued during the first part of this week. For a long period eruption had been impeded by the great quantities of solidified lava which had plunged in on top of the column during its subsidence in August. Gradually this mass was engulfed by the excess liquid brought from the depths by the ever-rising magma until the lava lake finally began to resume its normal character.

On Friday night, November 15, all the various pools described in recent reports, having expanded in area until they had joined, made once more a single lake of magma, occupying the entire bottom of the pit. It was coated with a thin black crust of solid or viscous lava which tore apart or cracked, flowing about in streams. Large cakes of crust were hurried into vortices, wherever there were areas of vigorous fountaining, and there were swallowed up. The hissing and explosive, wheezing sounds so characteristic of recent weeks had ceased. Only the ordinary plashing of the fountains was audible. While in many ways the lake was very active, all the more violent features of activity had stopped with the breaking up of the choked orifices in the thick crust.

Besides the fountain orifice of Old Faithful, which remained open, there were boiling pools near the margin of the lake at the E and W ends, and at the SE cove. Beyond the lake at the W was an open fountain orifice at about 20 feet above the level of the lake. Also at a higher altitude, possibly 75 feet above the surface of the lake, was a glowing gash on a ledge N of the margin. A little above the lake at the SE angle was an active fumarole from which a blue flame of burning gas rose, fluttering lazily.

The surface of the lake slowly rose and fell through a small range as was attested by times when the entire rim was broken and fire-marked with long glowing stalactites hanging from the shore bank. At other times overflow at the margin was seen.

From November 16 to 21 from the 370-foot level, the magma lake dropped 30 to 40 feet, leaving a fresh, vertical wall of this height about the margin. The peninsula emerged again, jutting out from the S margin into the lake, partly dividing it. With this subsidence came a partial rechoking of the vent accompanied by an increase in the apparent energy of eruption. Old Faithful boiled and splashed as strongly as on the evening of November 13, when it first resumed its normal character.

Only one earthquake has been recorded during the past week—a local shock of moderate intensity. This shock was felt at Hilo as a feeble tremor, but no one at or near the Volcano House reported it. It took place on November 15, from 12:09:00 p.m. to 12:10:28 p.m., H.S.T. Its origin is estimated at 11 miles from the Observatory. Theoretically its intensity here measures ⅛ the strength of a perceptible shock. This accords with the fact that no person hereabouts felt the jar, yet its origin appears to have been nearer this station than to the town of Hilo.

For 2 or 3 days microseismic motion has been constant and relatively very strong. This motion is generally considered to be due to disturbed meteorological conditions. In Japan, however, it has been thought that weak local earthquakes are fewer at times of marked microseismic disturbance.

The small earth vibrations of very quick period, attributed to the eruptive activity of the volcano, have been growing stronger of late, though they are not so strong as in mid-summer.

WEEK ENDING NOV. 28, 1912

During the week ending November 28 the pit was smoky, and the lava lake rose slowly. The surface configuration of the open pools in the crust changed from time to time.

Between November 22 and November 23 the lava surface was more than 390 feet below the rim of Halemaumau.

About 6 p.m. November 24 the depth below the east rim was 387 feet.

Two open pools in the crust appeared respectively W and E, boiling sluggishly. Occasionally the two pools were joined by a slow stream of lava moving eastward, sometimes bridged with crust. About 7 p.m. a narrow fork from this stream poured rapidly northward under the bank showing downward slope in the direction of its progress.

In the evening of November 26 from 8 to 11 p.m., the average depth to the lava surface was 380 feet.

A narrow stream poured from a small boiling pot near the S margin of the lake into the Old Faithful pool. Two chimneys above the level of the lake at the W end spouted jets of lava at intervals. A glow hole appeared N.

On November 28 the surface of the bottom of the pit was a single lake covered with thin crust. The crust was traversed by angular cracks through which occasionally miniature flows welled up. Less frequently blocks of crust broke up and foundered.

Three slight earthquakes have been registered during the week. A very feeble shock originating about 18 miles away was registered from 3:07:33 a.m. to 3:39:33 a.m., H.S.T., on November 21. Theoretically this had an intensity of about $\frac{3}{100}$ the minimum perceptible unit. A shock was registered on November 22 from 6:45:25 a.m. to after 6:45:52 a.m., H.S.T., reaching an intensity of about ⅛ the minimum unit. Its origin was about 27 miles away. On November 26 a shock was registered from 9:31:12 a.m. to 9:32:07 a.m., H.S.T., originating about 14 miles away. This also reached an intensity of about ⅛ the minimum perceptible unit.

Gas Collection by E. S. Shepherd:

This week introduced a procedure, inaugurated by E. S. Shepherd, that has since been the subject of important investigations in volcanology. The use of a vacuum tube, at a volcanic flame hole, to melt or break behind the flame and so collect the unburned volcanic gas is the ideal to which these arduous experiments were directed. The gases collected (Day and Shepherd, 1913; Shepherd, 1920, 1921, 1925b, 1938; Jaggar, 1917d, 1940) with vacuum tubes were always in different proportions of the six fundamental volcanic elements: hydrogen, carbon, sulphur, nitrogen, oxygen, argon—the fixed gases of magma—and their more or less oxidized products of atmosphere and hydrosphere. As water vapor and air were always present in large amounts, condensation created vacuum and sucked in more polluting air before effectual sealing could be done. The analysis assumed all free oxygen to be atmospheric, and appropriate amounts of nitrogen and argon with it. The combustible ingredients—hydrogen, carbon monoxide, and sulphur—remained in small proportions, and their oxides—water vapor, carbon dioxide, and sulphur dioxide—in large proportions. Immediately the query was suggested, to what extent are these three the products of more or less perfect combustion in the volcanic cupola and out of reach of the vacuum tube? Combustion may be going on deep within the lava column, for there is much oxygen available through the water-gas reaction, and in engulfed talus of rocks rich in iron oxides, and in cracks and vesicles. The definite flames used as locus of collection are not accounted for by the trivial percentages of combustible gases analyzed. The great contribution of these experiments, and vacuum tube collections made later, is that volcanism, including intrusion, involves the burning of elemental gases deep within the crust of the earth.

WEEK ENDING DEC. 5, 1912

The lava of Halemaumau rose at the beginning of the week, subsided slightly on December 4, and on December 5 had regained its level of approximately 360 feet below the SW station. The pool is vigorous within a rampart and platform of its own building, is active with many fountains, and on several sides the lava foam mounts within the talus to levels high above the pool, building conelets which flame like torches. The week has been notable for the final accomplishment by Shepherd of a dangerous task for which he has long been waiting an opportunity—namely, the collection of gas for analysis in vacuum tubes, from a flaming cone over the liquid lava.

The following measurements of depth have been secured:

Below SW Station	*Feet*
Dec. 1, 10:30 a.m.	359 (Fig. 5)
3, 11:00 a.m.	360 (Fig. 5)
4, 2:30 p.m.	approx. 368 (Fig. 5)
5, 12:00 noon	approx. 360

The fumes have been thinning so that the pool is often visible in daylight. At 10:30 a.m. December 1, there were three active coves NW, E, and SE, a stagnant crusted area in the middle, a small pool NE, and marked new overflows S, SW, and E on the platform about the lake showing that it was rising. A stream poured around a promontory from the SE cove into the midst of the eastern one, which was also the Old Faithful caldron. At 11:20 a.m. the middle crust rent apart, joining the coves into one large pool of liquid, with surface streaming E and W from the middle region, while the SE cove continued to pour a torrent into Old Faithful. The middle area stagnated and crusted after a few minutes, with streaming E and W from the newly formed blanket. There were spatter cones S of Old Faithful and on the S side of the extreme W end of the lake. Sixty feet farther west a ragged glow hole appeared in the talus with fumes above. At about 11:40 a.m. cracking and foundering took place at the outer edge of the lava platform next the talus SE, the liquid rising along the crack and spreading into a flow.

December 3, a survey of the pool yielded the following dimensions: active pool 360 feet long WNW-ESE by 150 feet wide on the W and 180 feet wide on the E. Outer platform 520 by 400 feet. Southeast cove 50 feet wide. Depth readings

	Feet
Dec. 3, 11:00 a.m., below SW station	357 and 361
2:00 p.m., below NW station	363

Spatter ramparts appeared W, SW, S, and N, but the promontory and stream between the SE cove and Old Faithful had disappeared. The whole pool was divided into eastern and western halves by a broad southern promontory, which extended itself into a blanket from which surface streaming spread radially. At the spatter ramparts there were caverns lined with stalactites into which the lava poured, as it did into the Old Faithful caldron. At 10 a.m. in a small open pot in the platform near its eastern margin a fountain built up a conelet. At the W end of the lake there was a cone at the edge of the pool and another farther back. At the edge of the floor N was an embayment whence a straight flow appeared recently to have poured to the northern lake margin.

December 4, at 2:30 p.m. the E conelet was 4 to 5 feet high with a N-S slot 5 inches wide spurting flame in its summit. The fumes were drawn up the E wall of the pit by the eddying E wind. The liquid lava of the lake had sunk about 8 feet making a wall about that high over the pool. There were some rim cracks about the platform, and the principal fuming places in the talus were W, NE, and SE. There were flaming cones at various levels also, two notable ones being a large one at the edge of the platform at the W end and the above-mentioned E conelet on the floor of the pit almost under the E station. A blanket covered the western lobe of the pool, and streaming was E and W from it. Clearly the floor had subsided.

Shepherd, equipped with vacuum tubes, determined to try to reach the eastern cone vent and collect the gas feeding the flame. Preparations for the descent were begun about 3 p.m. as follows. The locality selected was the NE corner of the pit starting from near the E end of the 1894 bench. The party making the descent consisted of E. S. Shepherd, H. O. Wood, and Alec Lancaster. Alec went down the upper slope below the 1894 bench and anchored a 50-foot length of rope ladder, made with hickory rungs, on a projecting ledge, a heavy auxiliary rope supporting it being lashed to a timber in a fissure at the base of the back slope of the 1894 bench. Alec called for a second 50-foot length which was lowered to him attached to a lighter rope by T. A. Jaggar, who took charge of paying out ropes and hauling them in as needed at the top of the cliff during the descent. Carrying the second ladder in a roll, Alec descended the first 50-foot length, made fast the second one, and released it. This 100 feet of ladder reached the inner talus. The whole route involved about 100 feet of rocky climb above 100 feet of ladder, and below that to the floor there was about 160 feet of talus.

At 4:30 p.m. Alec descended to the floor and walked out on the NE lava crust to the E conelet, finding a good walking surface, though red hot glow could be seen down some of the cracks. He returned and guided Shepherd and Wood down, the former roped to Jaggar above with an Alpine belt which Shepherd released when he had secured firm footing on the ladder and recovered again on his ascent. Alec carried a bundle of vacuum tubes (500 cc.) in a knapsack on his back. All three of the climbing party wore nose masks of rubber with exhaust valves, the inlets being provided with sponges moistened with pure water. These face guards were of the type used in sulphuric acid factories. The trail followed started at the same locality as in the descent by A. L. Day, E. S. Shepherd, and F. B. Dodge on May 28, 1912. Since that time, however, the talus had greatly subsided so that the upper rock climb was longer. During the descent the fumes on the NE were so thick above that Jaggar could see nothing of the party on the floor during the 1¾ hours that they were gone, from 5 p.m. to 6:45 p.m. The fumes, however, were less offensive below and caused no discomfort to the workers on the floor. The only unpleasant fumes encountered by the climbers were in the region of the upper slope and ladders. These came mostly from the N fumaroles at the edge of the floor and the talus to the W of the place of descent.

The party reached the floor without mishap and secured five samples of gas from beneath the flame at the top of the E cone: three of them Shepherd thought were excellent (Day and Shepherd, 1913; Jaggar, 1940). Each vacuum tube was attached to the end of a bamboo pole and carried out from the talus at the edge of the floor to the cone where the tip was inserted in the flame crack. The heat fused the bulb, admitted the gas from below the flame and then on withdrawal the flame was allowed to effect a temporary seal of the glass. On carrying the tube back to the foot of the talus it was sealed permanently with a gasoline torch.

The conelet has long sloping sides. Shepherd was impressed with the quiet of the fountains in the lake, which were quite active and noisy as observed from above. From below, the floor appeared to be 2 to 7 feet above the liquid pool. Mr. Wood noted the height of the Old Faithful dome fountains as spurting about 12 to 15 feet above the lake level.

On the morning of December 5 the pool was rising again and in places was overflowing. The equipment was recovered by Alec who descended the ladders again to the bottom.

Seven seismic disturbances have been registered since the last report, aside from the more continuous motions due to tilting, meteorological changes, and the throbbing of magma in the vent of the volcano.

Six of these have been extremely feeble local shocks, registered as follows:

	H.S.T.	*Distance*	*Intensity*
Nov. 30,	1:56:34 to 1:58:00 p.m.	17 miles	6/100 minimum uni
	5:02:18 to 5:03:12 p.m.	30	7/100
	7:00:41 to 7:01:15 p.m.	indeterminate	2/100
Dec. 1,	9:48:18 to 9:49:13 p.m.	22 miles	13/100
5,	2:45:15 to 2:47:10 a.m.	28	5/100
5,	8:11:35 to 8:13:13 a.m.	15	5/100

Besides these a near shock was registered. The intensity of this at the station was very small, but at the origin, about 280 miles away, it was a moderate shock. This began on the seismogram, sharply at 2:14:16 a.m., H.S.T., on December 5, and its second and third phases began distinctly at 2:15:06 and 2:15:53 a.m., H.S.T., respectively. Its motion continued for many minutes, dying away among current microseisms.

Microseismic movements and earth tilts have been normal, but a slight increase in the energy of volcanic tremors has been taking place in the past weeks.

Liquid Lava, Bench Lava, and Melting:

The discussion of the melting out of coves by the liquid part of the lake, when an adjacent blowing cone connects itself with the lake along a crack, opens a fundamental problem. This became the subject of extended discussion (Jaggar, 1917c; 1917d; 1920). Obviously the melting capacity of rising lava resides entirely in its vesicle gases. So-called liquid lava is a gas foam with gases in reaction. Within its own substance the deep parent lava is making vesicles from elements in solution which become gaseous when released from pressure appropriate to complete solution. No control in magma other than saturation, pressure, and temperature is known. Nuclear or electromagnetic transformations may play a part below the imagined crustal region of the earth, through which volcanism operates. Within the liquid glass of Halemaumau, however, gas is the heat bringer, its energy is quite incapable of melting the surrounding pit walls, and the glass congeals by internal crystallization to a paste. Within this semicongealed paste convectional wells and tunnels are kept open for the flux and fall of the gas foam eternally unloading its volatile products to the atmosphere. The lava lakes are shallow saucers with feeding shafts and drainage wells. The paste in which these tubes are maintained, itself rises and falls as the upper representative of the lava column. Most of the "melting out" observed within the crater pit is due to access of larger volumes of combustible gas from below, acting on the semicongealed substance of the lava column itself.

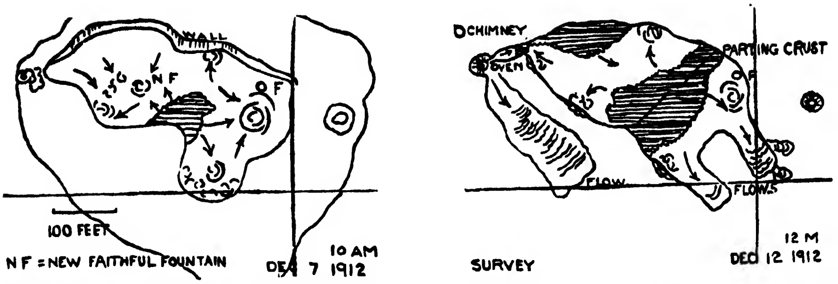
A new extension of eruption up a crack in old lava is primarily a constructive process, by tumescence and overflow. Volcanic erosion or destruction by melting may hollow out vertical shafts, afterwards revealed by engulfment, as pits along a rift when lava sinks away into the depths. Such destructive action by volcanism is quantitatively small. It is probably always correlated with a much greater constructive unseen submarine lava flow. The question, however, of subterranean destruction of the crust by intrusion, thereby accounting for some of the deep earthquakes and volcanic engulfments of history, is worthy of attention. A volcanologist studying the constructive work of lava in Hawaii is apt to wonder whether the much greater and more extensive process of intrusion is not also constructive by tumescence of the country rock and by addition of intrusions through the crust. If so, the doctrine of isostasy should allow for the weighting effect of such intrusive additions as a large process in orogenesis.

WEEK ENDING DEC. 12, 1912

The changes in Halemaumau during the week have not been great; the lava is rising and increasingly active with many fountains. The following levels have been measured:

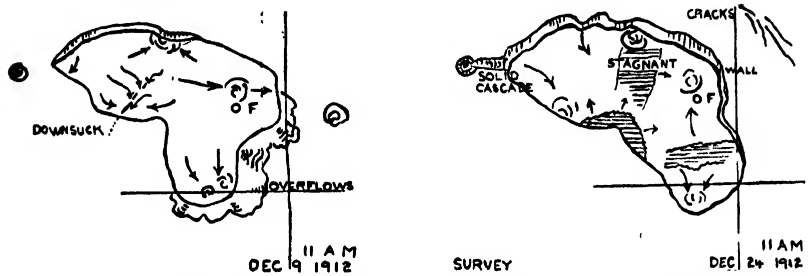
Below SW Station	*Feet (approximate)*
Dec. 7, 10 a.m.	366 (Fig. 6)
9, 11 a.m.	358 (Fig. 6)
11, noon	356 (Fig. 6)
12, 12:30 p.m., S cove	354 (Fig. 6)
12, 12:30 p.m., W end	349

On December 7 the fumes were dense from fumaroles W, NE, SE, and SW. It was rainy with winds veering from NE to SE which diffused the fumes and made seeing difficult, and a rain pattern of tails of white vapor arose on the hot platform around the lake. Shepherd's blowing cone at the E end of the floor around the pool appeared larger, with an enlarged opening, and there was a still larger cone under the fuming wall at the W end. The strong activity with many fountains recalled the July condition. Old Faithful was exploding heavily at intervals averaging 1 minute, and there was a second large rhythmic fountain in the SE part of the western lobe of the pool named New



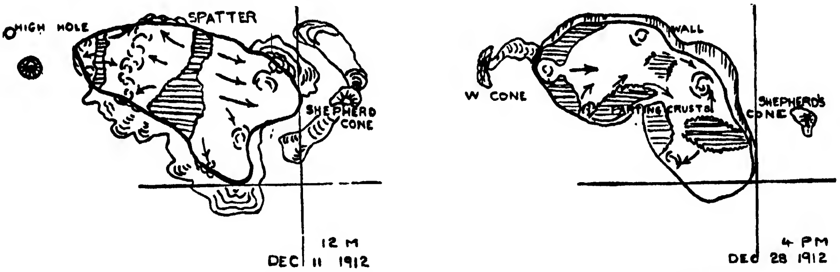
a. December 7; second rhythmic fountain formed New Faithful (NF).

d. December 12; flow from west oven and east bank.



b. December 9; overflows and border sink-holes: west bank up, east bank down.

e. December 24; crusted cascade and lowered lake.



c. December 11; complex streaming, overflowing and spouting cone.

f. December 28; double lake again.

FIGURE 6.—*Lava lake maps December 1912*

(*See* Figure 1.)

Faithful. The lake appeared to have sunk about 6 feet. There were coves NW, W, S, and SE, with ebullition and downsucking at their extremities, and SW a peninsula of scum extended out into the lake sometimes dividing it in two, then rending apart so that the two halves floated off E and W. The surface currents poured in all directions away from this peninsula, meeting others from the W and S. The S cove was enlarged.

Measured intervals between Old Faithful explosions were as follows: 55, 50, 65, 60, 70, 70, 60 seconds. Twice in this series the outburst was divided in two episodes coming respectively at the end of 45 and 20 seconds, and at the end of 15 and 45.

December 8, in the very early morning it was cold, and four pronounced vapor jets were conspicuous from the Observatory, on the high NE slope of Mauna Loa, near the two highest conelets. Three were between these cones, and one was below the lower cone, as seen in profile from the Volcano House district. The highest jet was the second from the summit, and, as this rose four or five times the height of the cones, it must have been several hundred feet high. The visibility and height of these jets are doubtless enhanced by atmospheric conditions. Two jets at this same place have been under observation since August 1912, but this is the first time we have seen four. There has been snow on Mauna Loa and Mauna Kea recently, and probably the cold weather on the mountain increases condensation in those vapors which contain water, thus making them more conspicuous. Since this date Mauna Loa has been very free from cloud and is generally visible, but the vapor jets have been rarely seen.

On December 9 the coves were less pronounced, the lake was a long oval with slight promontories SW and SE and a line of downsucking trending northeastward across the western half of the pool. The lake was active and rising with new overflow E and SE. A low bank bounded the pool on the N. The streaming was eastward about Old Faithful and toward the shore on the N, S, and W. Along the line of downsucking there were streams from E and W which met in the middle of the western lobe of the lake.

The morning of December 11 revealed pronounced rising and border overflows from the liquid part of the lake over the platform of chilled lava about it. Two hardened flows with festoons appeared to have broken out of Shepherd's cone and flowed NW and SW. Lumpy spatter ramparts were on the rim of the boiling lava, with considerable fuming S, SW, W, E, and N, and on all other sides the lake was brimming over. The W conelet was spouting lava from its summit in blobs, and above it a ragged hole in the wall glowed dull red within. The streaming was E and W from a band of crust across the middle of the lake.

December 12, overflows from the E and S coves were in action at 11 a.m. enclosing a peninsula between the two coves and prolonging the coves southeastward. The western conelet, at the other end of the lake, had broken open on the lake side and poured out a torrent of lava which flooded the SW part of the platform and made a straight channel for itself into the W end of the lake. The glowing magma poured through this channel from 11 a.m. to 1 p.m. meeting a W-flowing surface current in the lake at its mouth. Careful alidade measurement of the level of the cone cavern whence this stream poured, as compared with the other end of the main lake, showed that the cavern was 5 to 7 feet higher, and the molten river was literally pouring down hill. The glowing hole in the wall above was 3 or 4 feet higher.

At 3 p.m. the torrent from the W cone had stopped; it was bridged with black crust, and only a small pot of lava splashed lazily within the orifice of the half cone, which was shaped like the prompter's box in an opera house. It appeared to be ready to build up the broken half again with spatter. On the lake side of the bridge of crust, streaming was eastward from a ragged edge of skin. Streaming in the lake was E and W from the middle. There were spatter ramparts at three places along the SW border of the lake.

While the first flood from the conelet was overflowing the platform, the great weight of the advancing flow bent down the freshly crusted lava over which it flowed, so that the floor crust rifted along the front of the flow, and the glowing lava beneath repeatedly welled up in the cracks and merged with the lava of the flow. This showed that partially solidified flows constituted the upper layers of the platform over which the new flow was progressing. The size of the liquid pool and the width of the platform probably vary with the amount of heat supplied; an excess of heat brought up by the gases or otherwise should increase the size of the lake at the expense of the platform. In general at the coves and spatter ramparts the lava rushes in under the platform, while it is rising and spreading radially, not from Old Faithful, which is one of the downsucking areas, but from a quiet middle or western region of the lake. The relative areas of lake and platform may prove a useful measure of heat supply. An excess of heat may melt out new coves from the bench material along fumarole lines of cracking and so enlarge the lake without necessarily any addition of new lava from below, for the bulk of the bench lava so melted would be increased by fusion, the solidified rock being denser than the melt. Many observations have shown that a region of excessive and continuous overflowing on the bench adjacent to the lake, particularly when that overflowing is from border cones, will eventually develop into an arm of the lake.

From this discussion emerges the general problem concerning the source of all the rising and falling lava in Halemaumau during such an active period as 1907–1912. Apparently during this time there has been little new matter added to the crater prism. There have been no overflows, and the column merely rose and fell through a vertical range of 600 feet within a funnel narrow below and more than 1000 feet in diameter above. Approximately only 6,000,000 cubic yards of foamy lava have welled up into view at times of rising, only to solidify, shrink, and collapse within the pit at times of sinking. This same material may be melted again and expanded into the foamy condition with each new rise, unless the ebb is due to intrusive or extrusive drainage. Thus since 1894, previous to which time there was almost incessant overflow, a condition approaching adjustment has been reached in Kilauea, and perhaps all the phenomena of flux and ebb now observed may be explained by expansion and contraction due to addition or subtraction of hot gas from below.

Mr. H. O. Wood reports for the Whitney Laboratory of Seismology that five earthquakes have been recorded since last week, all local in origin, as follows:

Dec. 6, from 10:32:11 a.m. to 10:33:13 a.m. H.S.T. Origin distant about 15 miles, intensity 17/100 minimum perceptible.
Dec. 7, from 4:52:00 p.m. to 4:53:10 p.m. H.S.T. Origin distant about 26½ miles, intensity 7/100 minimum perceptible.
Dec. 7, from 5:06:02 p.m. to 5:07:54 p.m. H.S.T. Origin distant about 18½ miles, intensity 14/100 minimum perceptible.
Dec. 7, from 9:03:59 p.m. to 9:05:17 p.m. H.S.T. Origin distant about 17½ miles, intensity 6/100 minimum perceptible.
Dec. 12, from 8:53:49 a.m. to 8:55:33 a.m. H.S.T. Origin distant about 8¾ miles, intensity 9/100 minimum perceptible.

Microseismic motion and tilting have been strong during the past 3 days.

Suggestion of Tide Survey:

Even this early in the history of the Observatory, the desirability is indicated of hour-to-hour studies of tidal fluctuations of the lava lake. The later transit measurements at the time of development of crags and islands showed that the bench lava rose and fell with these tidal movements, even more systematically than the liquid lakes. In July–August 1919 these movements were measured (Jaggar, Finch, Emerson, 1924; Brown, 1925).

WEEK ENDING DEC. 19, 1912

The week at Kilauea has been marked by a slight recession of the lava, but the fumes continue to diminish and the activity to increase. The mechanism and size of the pool have been much the same as last week.

The levels below the rim have been approximately as follows:

	Feet
Dec. 13, 5 p.m.	354
14, 8 p.m.	350
15, 8 p.m.	353
16, 4 p.m.	357
17, 4 p.m.	363
18, 11 p.m.	365

These approximate levels are estimated by reference to the crust platform, which was overflowed on December 12, by survey 354 feet below the SW station.

The mechanism of the liquid pool from December 13 to 15 continued the same. A striking feature was the isthmus of skin which repeatedly formed across the pool from SW to NE, with streaming surface currents SE and NW away from it, and these rending it periodically.

On December 13 at 5 p.m. the activity was strong, and the isthmus of skin was forming, breaking, and reforming over the site of the former peninsula. The skin parted at intervals along a straight N–NE line, and the two halves broke away into floes which floated eastward and westward respectively and became engulfed. Possibly the tearing at intervals was a function of the rhythmic rise and fall of the pool; it happened every 20 to 30 minutes. A skin would immediately re-form across the middle region, which appeared to be the place of rising or inflowing, just as earlier in the year the N and W coves appeared to be the region of inflow.

On the night of December 14 the lake was overflowing most remarkably. There were moving overflows SW and E, and a pot in the wall several feet above the level of the platform south discharged a great pahoehoe lava flow over the southern part of the platform. The S spatter rampart of the lake was punctured by the liquid, a flow sputtered through the hole, and lava pounded in a cave beneath the rampart. Glowing rims of flows on the floor appeared in many places. This was the climax of overflowing for this month.

The overbrimming ceased on December 15 and slow subsidence started which from 7 to 9 p.m. was accompanied by another discharge of lava into the pool from the cone at the NW end, just as described for December 12. This river of lava poured down a slope continuously from the ruptured cone, in a stream 10 to 15 feet wide and 40 to 50 feet long, at 4 to 6 miles per hour. The course of the stream was sinuous, and it undermined the cone so as to break away its N wall and throw off a fork on to the platform N in the course of the evening. The lake was about 6 feet below its banks.

December 16, this stream was crusted over, but in the afternoon fountaining was greater. At 2:45 p.m. the lake was 5 feet below its bank at the mouth of the crusted river, but by 5:15 it had risen 2 feet. A solidified festooned flow occupied the place of the western torrent.

On December 17 and 18, subsidence continued with the same general features otherwise, with maximum sinking in the morning and restoration of level in the afternoon and night. It is very desirable to make hour-to-hour studies of these seemingly tidal fluctuations of the lake throughout the 24 hours for a considerable period, but the staff of the Observatory is not yet large enough. On December 18 the fumes were somewhat less dense.

Mr. H. O. Wood reports three earthquakes in the past week, all local. Hereafter we shall employ the Cancani dynamical scale of intensity for seismic motion. The hypothetical *minimum perceptible shock* and its fractions hitherto used is not accurate. Its dynamical equivalents have never been determined and they are subjective.

The scale devised by Cancani is the best intensity scale in that it divides the energy range systematically and proportionately basing its divisions upon a sufficiently accurate physical measurement of the *acceleration* of the seismic motion. The Cancani scale can be employed only where seismometric records are available, and hence, despite its positive merit, it has been little used.

The Cancani dynamical scale of seismic intensity is as follows:

		Acceleration (Mm/Sec/Sec)
I.	Instrumental	0.0– 2.5
II.	Very slight	2.5– 5.0
III.	Slight	5.0– 10.0
IV.	Sensible, mediocre	10.0– 25.0
V.	Rather strong	25.0– 50.0
VI.	Strong	50.0– 100.0
VII.	Very strong	100.0– 250.0
VIII.	Ruinous	250.0– 500.0
IX.	Disastrous	500.0– 1000.0
X.	Very disastrous	1000.0– 2500.0
XI.	Catastrophic	2500.0– 5000.0
XII.	Great catastrophe	5000.0–10000.0

Grade IV is ordinarily the minimum perceptible intensity, and in grade XII the acceleration reaches that of terrestrial gravitation.

The term acceleration means the rate of change of speed in the *motion of vibration* of earth particles. It is neither a rapid motion of the earth particles nor a slow motion which produces the jarring sensation of an earthquake, the overturning of objects, or the wrecking of structures. There is no effect of this sort in a vehicle moving wth a uniform speed; it is, rather, a sudden jerk or rapid change from rest to speed the instant following, or vice versa. It is *change of speed* bringing inertia into play which produces earthquake phenomena; the *rate of change of speed*, usually measured in millimeters per second, is the *acceleration*. The Cancani scale depends upon this.

The first earthquake measured this week was not registered by the major tromometer owing to a slight accident to the writing index of this instrument. Though very feeble it set off the ordinary seismograph starting mechanism. It occurred in the night December 15–16.

The second and third were registered as follows:

Dec. 17, from 7:25:23 a.m. to 7:26:45 a.m., H.S.T.
Distance of origin about 12 miles.
Intensity grade I Cancani scale.

Dec. 17, from 3:21:08 p.m. to 3:25+ p.m., H.S.T.
Distance of origin from 13 to 15 miles.
Intensity grade IV Cancani scale.

No one has reported feeling this latter shock. Microseismic motion, tilting, and volcanic vibration have been of normal character during the past week.

The Bench Magma (or Epimagma):

This week produced the first definite mention of a rise bodily of the platform surrounding the lava lake. It is here mentioned as "bodily flotation". There is also a description of glowing holes emitting lava in the talus high above the lake level. This had been seen and noted many times in 1912. The word flotation had been used in connection with so-called "floating islands" by F. A. Perret; "upthrust" would have been better (Perret, 1913a).

The rising and falling of the body of the lava column, as an incandescent partly crystalline paste has been described and figured by Jaggar (1917d; 1920). This upright cylinder of magma is the bulkiest part of the upper lava column. The liquid froth is a foam rising through it along tubes maintained by the melting capacity of a thermal circulation. Where this expanding foam finds crevices, as between blocks of a talus within the crater pit, it will rise through the small open spaces and fill the talus with a lava cement. The talus accumulations lie above the marginal contacts of the lava column with the country rock. This is a place of much friction and consequent escape of the hot foam, which makes tubes within heat-insulating shells of its own substance along any small crack or crevice where it can push upward. Within these honey combs or small dikes of the wall crack, the expanding foam can rise higher than the lava of the main lake, because the latter loses gas more rapidly through its many fountains. Hence when glowing holes, spiracles, and spatter cones appear in marginal cracks or in high talus around the edges of the pit floor, the height above the middle region to which such seeming violation of hydrostatic principles can go is dependent upon an equation between sizes of orifices, retention of gas, and percolating power; the marginal rise in small vents is somewhat similar to the rise of beer around a loosened cork. A talus accumulation thoroughly soaked with hot lava from below becomes an integral part of the lava column. If the crater wall is a funnel, and the talus is all cemented with lava paste, a rise of the lava column will cause the talus to part from the wall and may leave an open chasm on the wall side.

WEEK ENDING DEC. 26, 1912

The subsidence noted last week at Halemaumau continued to December 22, when a rising of the lava level began which appears to be still in progress, though no very rapid rise has as yet taken place. The measured levels below the rim were:

Dec. 22, 4:30 p.m., below NW station	370 feet
24, 4:30 p.m., below SW station	349 feet (Fig.6)

On December 22 the form of the pool was an irregular oval pit within a much larger platform, the walls being about 20 feet high. At the west end of the platform was a fuming cone 8 feet high with glowing lava within, the conelet being breached on the east side toward the solidified cataract which had poured down the slope into the lake on the evening of December 15. There were cracks about the edge of the platform under the talus above, a second conelet (Shepherd's) on it at its east end, and glowing holes in the higher talus N, SE, and NW.

The surface currents had changed from the condition noted last week so that the main drift was now from NW to SE. A peninsula of crust still extended into a bridge of stagnant blankets from the SW side of the middle of the lake, but there was a pronounced outpour from the cavernous spaces under the wall at the NW which dominated the surface flow of the western half of the pool and seemed to be a continuation of the tendency to eastward streaming begun there at the time of the cataract of December 15. The surface currents otherwise poured against the S and SW walls and from all sides into the vortex of Old Faithful.

On the morning of December 24 the wall about the pool seemed not to have changed, but the measurement revealed a rise of 21 feet (Fig. 6). This can be accounted for only by supposing error in measurement or bodily flotation (upthrust) of the floor prism. The fumes about the talus seemed to have increased during the last few days without any marked effect of the rise, which ordinarily causes the fumes to diminish. The fountaining was fairly active, increasing in the afternoon. Surface flow was from the W end. There was a stagnant area across the middle of the lake and some sliding of rocks on the talus W. The edge of the platform NE was cracked. Out from the S cape the currents streamed radially.

On the afternoon of December 25 there were no marked changes. The surface flow was from the

N and W banks toward the E, with local inpouring toward the banks on the S and SW. The wall over the pool appeared 15 to 20 feet high, and there was a strong spatter rim in the middle of the SW side of the lake. The lake was reported rising and increasingly active in the night. A stagnant area protruded from the SW cape and across the middle of the S cove.

In the Whitney Laboratory only one earthquake has been registered during the past week,from 11:15:00 a.m. to 11:16:03 a.m., H.S.T., December 21. This was distinctly felt by Mr. Wood at the Observatory as a single light shock. Windows rattled slightly. Motion was perceptible for 1 to 2 seconds. The intensity was midway in the range of Grade IV of the Cancani scale. The origin probably was less than 5 miles from the Observatory.

The rapid vibratory motion considered due to the eruptivity of the volcano, though irregular and sporadic, has gradually increased in intensity until it is as strong as some of the minor earthquakes hitherto reported.

WEEK ENDING JAN. 2, 1913

Until December 28 the level of the lake at Halemaumau remained stationary or rose slightly. From that time it has fallen about 30 feet, leaving a cavernous pit with sluggish glowing lava in its bottom and nearly vertical walls scarred with the shore marks of subsidence. The subsidence of the week has been marked, and there is no sign that it has yet ended.

The levels have been approximately as follows:

			Feet
Dec. 26, 1912,	5:30 p.m.,	below NW station	372
28, 1912,	10:30 a.m.,	NW (Fig. 6)	370
31, 1912,	3:00 p.m.,	N	388
Jan. 2, 1913,	3:00 p.m.,	N	395

On the evening of December 26 the streaming was mainly from the NW; the SW promontory was very sharp-pointed with a fan of blankets attached to the shore. Streaming was eastward, into Old Faithful, and against the S and WSW banks. The general appearance was the same at 10:30 a.m., December 28. The fumes were thin, densest at the W end, and there were black wrinkled skins on the surface of the pool but no cracking crusts about the shore lines. The fountains made a noise of steady splashing, and the wall about the pool appeared about 12 feet high and was scarred at several levels with lines of spatter marking; there were clinging stagnant blankets at the NW end enclosing a round cove of boiling melt, and the general condition suggested slow rising. At 4 p.m., December 28, fountain activity was greater than in the morning, and remarkable semicircular blankets were forming around the SW cape with radial streaming out from the semicircle; now and again the half circle of skin tore away from the bank, the fragment floating out to be engulged in the fountain of Old Faithful.

December 29, conditions were much the same, but a sinking began about December 30 which was proved by survey the afternoon of December 31. At first there was a clear view, and a survey of the pool was attempted, but the fumes began to swirl about 3 p.m. so that thereafter there were no clear views from the S and E and only occasional brief views from the northern stations. Vertical angles determined the SE boiling region to be 388 feet below the N station and 350 feet below the much lower NE station which is located on the 1894 bench. This implied a lowering of about 18 feet in 3 days.

There was no observable depression of the platform, and the SW cape had become a peninsula and presented a terraced appearance growing larger below and nearly dividing the lake in two. Both streaming and fountaining had decreased. Peripheral cracks were noticed in the platform with sulphur deposition at the lips. The fumes were thicker than at any time recently, and several small avalanches of talus were heard, a sure index of sinking.

January 1, the pool appeared to be still sinking, and on January 2 there was every evidence that it was approaching the 400-foot mark. The fumes were dense, the division of the pool by the peninsula and the stream around the end of it recalled conditions in November, and a shore mark more than half way up the wall showed the previous week's level high above the present lake. The emergence of the peninsula by subsidence just where surface blankets have been forming next to the shore confirms the supposition that the cooling effect of this submerged peninsula produced the blankets, just as the submerged island reported in 1911 by Mr. Perret caused a peculiarly shaped blanket above outlining that area of submergence.

Mr. H. O. Wood reports two very feeble local eartquakes during the past week as follows:

Dec. 29, from 1:36:01 a.m. to 1:37:07 a.m., H.S.T.
Intensity ~~I~~I of Cancani scale.
Dec. 31, from 8:45:54 a.m. to 8:47 ± a.m., H.S.T.
Intensity ~~I~~I of Cancani scale.
Distance of origin about 25 miles.

A visit to the Observatory on December 28 and 29, 1912 was made by Dr. W. T. Brigham, Director of the Bernice Pauahi Bishop Museum of Honolulu.

WEEK ENDING JAN. 9, 1913

The week January 3 to 9 has shown daily fluctuation of level of a few feet, with the position at the end of the week very much as it was at the beginning. The work of the station has been made more systematic, and certain changes in daily routine will make it necessary to end the week hereafter on Tuesday. During the past week hourly observations of the crater for parts of every day have been instituted, and on one day hourly observations were made for 22 consecutive hours with angular measure of depth from the Instrument House (Pl. 1d) toward a point in the S cove where the liquid rose and fell in contact with a nearly vertical wall.

The levels below the north Instrument House (Old Rest-house adjacent) for the week have been as follows:

	Feet
Jan. 3, 10 p.m.	383
4	379
5	374
6	376
7	377
8	382

On January 3 an active pool was partially divided by a southern peninsula, with vigorous fountains, and streaming from under crusts, which from time to time were rent away from the shore to which they were attached.

A quick survey was made from the NW station and N Instrument House. The lava pool was low and small. One small avalanche was heard between 9:00 and 10:00 p.m. Camping at the pit station was started.

January 4, an occasional isthmus of crust formed across a fingering extension of the lake at its W end.

At 9:30 a.m. the alidade was set up in the N Instrument House for a test of hour-to-hour vertical angles on the S cove of the lake. The lava surged against the wall at the point observed in the telescope, and depressions were read to an accuracy of 0.5 foot. Readings in the forenoon were made at approximate half-hour intervals, and a few readings were made at night working from the same pencil-marked position on the shelf of the Instrument House. A point on top of the inner wall was observed and measured, as well as the lake level, to test possible bench movement.

Changes of depression of lake and inner bench were as follows:

Time	*Depression in same vertical plane, of bench above S cove below Instrument House*	*Depression of S cove, lake, in feet below Instrument House*
9:30 a.m.	—	386.5
10:00 a.m.	—	385.0
10:30 a.m.	—	379.5
11:00 a.m.	341.5	380.5
11:30 a.m.	341.5	379.5
12:15 p.m.	341.5	378.5
12:50 p.m.	341.5	376.0
10:00 p.m.	—	379.5
10:05 p.m.	—	378.5
10:21 p.m.	—	378.0
10:40 p.m.	—	378.0
10:45 p.m.	—	376.0
11:00 p.m.	—	376.0

The survey was checked for location of the S cove by intersections of horizontal angles from N and NW stations.

Intervals between Old Faithful outbursts in seconds about 10:30 p.m. were: 24, 40, 33, 13, 14, 8, 36, 28, 26, 16, 40, 21, 15, 35, 15, 46, 12, 14, fumes, 56, 10, 30, 19, fumes, 35, 22.

Fountains more active, and streaming faster; current sluggish in strait, but more rapid toward Old Faithful, peninsula slowly submerging under folded blankets piled up along shore about 1:00 p.m. At 10:45 p.m. this crescent of crust around the peninsula broke up and was transported eastward, cracking and foundering. There was a distinct temporary rise of liquid along the wall, as though occasioned by displacement of foundering crust.

At 12:30 p.m. January 5 this crust was thick enough to bear a small flow which rose from the pond cut off by the isthmus, broke over the isthmus and its shoreward extensions, and poured into the lake, eventually breaking down the crusts beneath it.

Measurements of lake depression at S cove below Instrument House gave the following:

	Feet
9:00 a.m.	379.0
10:20 p.m.	374.0
10:30 p.m.	380.0
10:45 p.m.	375.5

A bridge of crust formed across the W end of the lake during the preceding night and broke up between 9:00 and 10:00 a.m. At 12:30 p.m. the bridge formed again, and also a cuspate semicircle of crust on the lake around the S peninsula. The lava welled up at the W end and flowed over the top of the hard crust, broke it down, and sank it, and merged everything into one open pool.

Inspection of the liquid lava through the inverting telescope of the alidade, set on the middle stadia hair, showed that it sank at 10:55 p.m., after remaining stationary for 10 minutes. It lowered half way to the upper stadia hair. At 11:00 p.m. it lowered to the upper hair. At 11:02 p.m. it was above the upper hair. At 11:05 p.m. it was rising half way to the middle hair. At 11:08 it again sank to a point above the upper hair. When the crust around the peninsula broke, the liquid lava rose again.

January 6, sinking was shown by the height of the rocky promontory dividing the two halves of the pool and by the increase in fumes from all the fumaroles in the talus.

At 10:35 a.m. a heavier avalanche was heard to the SE, and one at the W at 11:15 a.m. Stalactites appeared around the edges of the pool. Both New Faithful at the W and Old Faithful at the E were making rhythmic fountains, there were baby fountains in the W pool, at 2:00 p.m. violent churning with inflow to the bank under overhanging stalactities occurred, and at 5:00 p.m. the bursting domes of Old Faithful became double and triple, and there were many baby fountains during the intervals between its outbursts. There were many alternations during the day between formation of stagnant crust and its break-up.

The intervals (in seconds) between times of main outbreak of the two rhythmic fountains were:

Old Faithful (very violent)	*New Faithful*
38	27
20	56
53	30
—	50
03	18
33	55
50	26
—	45

On January 7 and 8 stalactites and overhanging cavernous spaces around the margin indicated additional sinking, the lava flowing in or out beneath the platform in several places as though extending far beyond the visible lake.

Measurements and observations indicate that pulsations of rising and falling are going on from hour to hour, that at times of lowering there is accentuated break-up of crust and streaming under the bank, and at such times avalanches fall. At times of rising the hollows under the bank fill up, stalactites are submerged, streaming becomes sluggish, quiet crust or skin forms on the lake, and sliding on the talus slopes ceases. During rising spells the pit becomes less smoky. With change of wind the eddy brought noxious sulphurous and sulphuric acid gases to the Instrument House. At times a line of traveling fountains would form in the W pool. There were fuming places and flaming chimneys in the talus and among the benches on several sides of the pit, some of them ragged sulphur-stained holes, glowing within, showing fume by day and flame by night.

During the week eight earthquakes have been registered here, as follows:
Jan. 4, from 8:49:58 a.m. to 8:50:49 a.m., H.S.T.
Intensity, low I, Cancani scale.
Jan. 5, from 1:47:17 a.m. to 1:48:05 a.m., H.S.T.
Intensity, low I, Cancani scale; origin distant about 31 miles.
Jan. 6, from 00:25:14 a.m. (midnight) to 00:26:43 a.m., H.S.T.
Intensity, high II, Cancani scale; origin distant about 13 miles.
This shock was energetic enough to start the ordinary seismograph.
Jan. 6, from 8:52:03 a.m. to 8:52:52 a.m., H.S.T.
Jan. 6, from 11:28:51 a.m. to 11:30:02 a.m., H.S.T.
Intensity, low I, Cancani scale; origin distant about 15 miles.
Jan. 6, from 5:51:47 p.m. to 5:53:13 p.m., H.S.T.
Intensity, high III (possibly IV), Cancani scale; origin distant about 8½ miles.

This shock started the ordinary seismograph. Its energy reached, or exceeded, the minimum limit of intensity perceptible to the human senses, for it was felt distinctly at Kapapala Ranch.

Jan. 6, from 6:15:43 p.m. to 6:17:04 p.m., H.S.T.
Intensity, medium I, Cancani scale; origin distant about 20 miles.
Jan. 7, from 5:15:27 a.m. to 5:52:26 a.m., H.S.T.
Intensity, low I, Cancani scale; origin distant about 25 miles.

Preliminary Lava Tide Measurement:

At the beginning of 1913 a camp was made at the northern rest house near the edge of Halemaumau, and on the edge was built a shelter open toward the pit with a counter or table on which the alidade could be set for measurement of vertical angles on such objects as glowing cones and splashing grottoes. With prolonged night work it was possible to make a preliminary test of the lava tide. On the day of most complete measurement there was sudden rising at about 6:00 a.m., 11:00 a.m., and 6:00 p.m. of approximately 5 feet. In the intervals there was slow subsidence. This inaugurated the idea of the tide measurement of 1919 (Pl. 32).

WEEK ENDING JAN. 14, 1913

The lava lake from January 8 to 14 has subsided slowly and irregularly, with intervals of slow or rapid rising. During the later part of the week the only times of measurement from the Instrument House have been at night or in the very early morning, when the outline of the glowing lake could be seen through the fumes. In the daytime the fumes obscure the view.

A chart constructed for the period January 4 to 11, shows the times of observation and heights of lava surface in feet, measured at the contact of lava and wall at the extreme end of the S cove where for some time the lava has been streaming toward and under the bank. This cove is opposite the Instrument House, and the alidade could be mounted on a marked line on the sill, in the house, and directed hour by hour to the same point on the shore of the pool, each vertical angle read being compared with the reading of the level bubble, and the horizontal distance checked by survey from time to time from three stations. The shore line of the S cove was eating back at the rate of about a foot a day. The fluctuations in level are referred to the concrete pier in the Technology Station which stands a few score feet back of the Instrument House and was determined by the U.S. Geological Survey last spring as 3700 feet above mean sea level. The sill of the Instrument House (Pl. 3d) is on the same level, and measurements have been made of the depth of the lava surface, where fluid or covered with only a thin flexible skin, below this sill—*i.e.*, below the 3700-foot contour.

The following shows the fluctuation of depression levels:

		Feet		*Feet*
Jan. 7	6 a.m.	379.5	11 a.m.	378
	7	380	12 m.	377
	8	380	1 p.m.	378
	9:15[5]	381.5	2	379
	10 a.m.	383.5	3	379

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[5] **Readings after the hours occasioned by waiting for fumes to clear.**

		Feet
	4 p.m.	380.5
	5	380.5
	6	376
	7	376.5
	8	376
	9	376
	10	377.5
	11	378.5
	12 mdt.	378
8	1 a.m.	378
	2	379
	3	378
	7	374
	8	376.5
	9	378.5
	3 p.m.	378.5
	10 p.m.	383.5
	11	384
9	6 a.m.	382.5
	7	381.5
	11:30 p.m.	381
	12 mdt.	384
10	2 p.m.	385.5
	9:20	380.5
11	7 a.m.	385
	8:30	383
	10	384
	1:30 p.m.	392
12	11:25	388.5
13	6:30 a.m.	390.5
	10:30 p.m.	390
14	6:20 a.m.	392.5

Because of delays occasioned by thick fumes, the later readings are irregular and frequently after the hour. The most interesting series of observations is the period of 22 hours January 7 to 8; the air was relatively clear and the lava column receded from 6 to 10 a.m., rose quickly 5½ feet 10 to 11 a.m., sank from 11 a.m. to 5 p.m., rose 4½ feet from 5 to 6 p.m., sank slowly until the early morning hours, when again there was a relatively sudden rise of 5 feet. This pulsating mechanism will be the subject of more continuous study in the near future, it is hoped, as soon as the return of rising conditions clears away the fumes and makes regular observation possible.[6] More instrument shelters are needed, as in stormy weather this kind of work can be done only under cover.

The lake, in spite of its low level, has been a magnificent spectacle at night, on account of the deep inner pit it occupies below the platform of its recent building, and its peculiar horse-shoe shape around a peninsula which protrudes from the SW. From a cavernous fingering extension at its W end where there is an isolated small boiling pond, the whole surface streams majestically from W to E and then S in a broad river of fiery melt, past Old Faithful which engulfs a portion of the dark blankets, and then on to the end of the S cove where the whole stream quietly pours, surface blankets and all, *under* the platform, for the full width of the pool, and disappears. The *platform*, or bench of overflow of December 14 last, stands now more than 40 feet above the molten flood, and the streaming surface pours under a nearly vertical wall of that height scarred with many recent shore marks. The surface currents flow out from the shore elsewhere, but the peculiar little pond at the W end, separated from the main pool by an isthmus of crust most of the time, exhibits a westward-flowing drift in toward the western flaming cones and fuming talus.

In the early morning of January 8 the rise of a few hours followed by a nearly stationary condition produced a spatter bench 1 to 3 feet wide around the E end of the pool. There are definite symptoms of a stationary condition, or of rising or sinking, which can be detected with a little practice. During sinking, stalactites hang down into the pool, where it flows under or from under the bank. The crusts around the shores, notably recently about the western half of the lake, sag when the liquid subsides under them, crack along the shore line, float out a little way, and founder. Slides in the talus mark subsidence and may become avalanches when sinking is rapid. The fumes from the fumaroles in the talus become denser when sinking begins and less dense on a rise. Stationary levels of the liquid record their duration in spatter benches which grow 1 to 5 feet wide. With rising, the cracking and foundering of shore crusts cease, and on the shore of inflow the stalactites are drowned, blankets pile up, and small flows trickle over the spatter benches. All these things were observed during January 7 and 8. The W arm of the pool is marked by a pattern of boiling and migrating small fountains highly luminous, the E arm by tearing blankets which spread apart and reform, stream down the east-flowing current, and are interrupted only by the double, triple, and sometimes quadruple domes of Old Faithful.

On January 9 the W pool was narrowing by accretion where the streaming flowed away from the

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[6] Done in the summer of 1919 (Jaggar, Finch, and Emerson, 1924; Brown, 1925).

bank, while the S cove was extending itself by erosion where the stream flows under. Flapping skins and temporary protuberant crusts form along the W shore line whence the current flows, occasionally tearing them away.

A lowering was marked by the usual signs January 10. A round hole stained with sulphur formed in the high S talus where one of the largest of the December fumaroles has recently diminished in activity. The downsucking tendency at Old Faithful seemed to be diminishing, the stream moving past it to the S cove.

January 11, with the increased viscosity of the surface lava, which accompanies a lowering, the fountains became more noisy, probably by confinement of gas in the stiffer fluid. Several brilliant flame chimneys were noticed at the W end, one with a filagree cone over glowing lava within. Rock slides and two strong avalanches were heard between noon and 1 p.m. The humidity of the recent fortnight of rain has brought into prominence the aureole of vaporing cracks all around Halemaumau, about the same distance back from the edge as the "postal card" rift.

The lowering was conspicuous as portions of the inner cup were carried out of sight from the north Instrument House, and the lake was surrounded by obviously higher inner cliffs. There were numerous rock slides, and along with strong fume Pele's hair drifted into the shelter.

Active rising at 11:30 p.m. January 12 drowned the southern stalactites; fountaining was vigorous and streaming rapid.

Recovery by several feet brought back into view those portions of the W pond which had lowered out of sight.

At 11:30 p.m. January 13 the western half of the pool showed a line of downsucking and infolding blankets trending NE-SW across its middle. The streaming surface skins and migrating fountains moved from both sides toward this line, which appeared to be a weak specimen of what produced the "traveling fountains" noticed last July and a number of times since 1909.

January 14, at 6 a.m., the pool was again sluggish and receding, with parting crusts breaking away from the shores, and talus slides.

Shepherd's cone on the eastern platform has developed a large circular hole in its midst. These circular fumarole cavities, formed over surging lava beneath, resemble on a small scale the circular pits such as Halemaumau and the 16 pits which extend SE from the crater of Kilauea. It is a question of interest whether both large and small circular pits are produced by similar mechanism and to find out what that mechanism is.

On the beds of Pele's hair (Pl. 5b) near and on the western and highest edge of Halemaumau the writer found blobs of blackish-green basaltic glass on January 14. These were in irregular roundish splashes and in pencils 3 to 4 inches long. This edge is at least 100 feet above the high level of lava of January 4, 1912, and to leeward. These spatters must have been thrown up at that time. Some weighed several ounces, and all were within 15 feet of the edge of the pit.

During the 6 days five local earthquakes have been registered as follows:

Jan. 11, from 12:56:05 a.m. to 12:57:04 a.m., H.S.T.
Intensity, very low I, Cancani scale; origin distant about 25 miles.
Jan. 11, from 10:09:04 p.m. to 10:10:42 p.m., H.S.T.
Intensity, very low I, Cancani scale; origin distant about 18 miles.
Jan. 12, from 2:03:01 a.m. to 2:03:54 a.m., H.S.T.
Intensity, low I, Cancani scale; origin distant about 27 miles.
Jan. 13, from 1:57:18 p.m. to 1:59:26 p.m., H.S.T.
Intensity, high III, Cancani scale; origin distant about 14 miles.

This shock was sufficiently strong to start the ordinary seismograph, but not to make a serviceable record. The shock was not felt at the Observatory, although its seismometric occurrence was known instantly, showing it to be just below the minimum perceptible intensity.

WEEK ENDING JAN. 21, 1913

This week Halemaumau lake has been rising, after some further sinking to the 399-foot mark at 11 a.m. January 16. On January 21 the lava had risen to 366 feet below the north Instrument House.

The levels have been higher at night than in the morning, with depression as follows:

	7. a.m. Feet	9 p.m. Feet	
Jan. 14, 1913	392.5	—	
15	—	389	
16	392	391.5	
17	389.5	386	
18	387	378	
19	—	378	(Pl. 11a)
20	376	373	
21	368.5	366	

The maximum and minimum depressions per day (the measurements being usually from 6 to 6 a.m. and more irregularly in the afternoon and evening) showed the greatest range after the marked rise began. Thus on January 15 the depth below rim varied between 388 and 392 feet; on January 16 between 399 and 390 feet; on January 17 between 391 and 386 feet; and on January 18 between 386 and 375 feet, the range increasing from 4 to 11 feet. These were measured at the same point on the shore. The range thereafter decreased to 6 and 4 feet on January 20 and 21, respectively (Pl. 11a). Measurements made on different parts of the lake have not been closely accordant, and probably the W end, which was a separate higher pool last October, and from which the surface streaming proceeds, is higher than the E end.

The form of the lake has not materially changed during the week. Rising and overflowing the spatter benches within the inner pit has increased the width of those benches, especially on the E side of the peninsula and along the E bank. The streaming continues from W to E. A radial arrangement of slowly tearing blankets makes a geometrical pattern on the surface of the lava against the E shore of the peninsula. The sweep of the current around this peninsula suggests how the latter by further undermining might become an island.

January 18 was a very rainy day, and at 8 p.m. the writer was standing in a heavy cold downpour watching the lake from the E station. The shower had been falling on the glowing lava perhaps 10 minutes when suddenly a violent change came over the face of the pool. The rain was so voluminous and cold, chilling the surface blankets, that the E arm of the lake became dark and stagnant, excepting the Old Faithful fountain. The streaming from W to E stopped. The W pool started streaming in the opposite direction. At the same time tremendous fountaining began at the W end, splashing high on the banks, and a milder similar effect was seen all around, a notable white glow appearing in the fountains which developed under the bank in the S cove. The pool hissed and rumbled, then quieted and darkened, showing very few of the small fountains, and covered itself with thick blankets. Old Faithful broke through as usual, and slowly the eastward flow was resumed. Then the pit filled with water vapor, and the pool became invisible.

About noon January 21 the writer was working in the north Instrument House when he noticed the NE talus under the remnant of the 1910 bench was working—that is, rocks were tumbling into the flaming NE fumarole below. Noisy avalanches began to fall at 12:10 p.m., alternating with the clatter of rolling boulders. The first large fall was composed of the shelf of 1912 material (Jan. 4, 1912) just under the 1894 bench at its western end. At 12:16 p.m., a great tumble shook the Instrument House and carried away the E end of the bench which lies 60 feet under the Old Rest House on the N brink. I was watching the spot, and the end of the bench quietly sank away like a fluid; afterwards there was a terrific crash and clouds of brown dust, and the edge of the pit trembled violently. The lava was rising, and the fall was induced probably by the undermining of the foot of the slope by the fumarole.

Regular night and day photographing of the lake has been instituted, a journal sheet of daily measurements is being prepared, and the Instrument House and crater station are being remodeled.

The lava lake by survey January 20 was crescentic about a peninsula protruding from the SW. Measured rectilinearly it was 335 feet long, 175 broad E, and 128 broad W. Measured on the curve it was 413 feet long. A western pond or fingering extension was 20 feet wide. The rocky peninsula extends 40 feet from the rim of the platform which is 20 to 30 feet above the pool, but extends more than 80 feet if one counts the spatter rim of the pool and breaking crusts. This marginal shelf of recent construction by overflow is 60 feet wide at the E end and averages 10 feet wide.

During the past week no earthquakes have been recorded. During about 36 hours January 18 to 20 there was a noticeable increase in the frequency of groups of volcanic vibrations, and at times maxima among these waves were definitely stronger than usual.

WEEK ENDING JAN. 28, 1913

The lava pool has fluctuated only 1 or 2 feet per day and as a whole has subsided about 10 feet below the highest level of the last fortnight (366 feet down on Jan. 21). The levels for the week below the 3700-foot contour were:

		Feet			*Feet*
Jan. 22	8 a.m.	369.5	Jan. 25	8 a.m.	375.5 (Pl. 12a)
22	10:30 p.m.	372	25	5:15 p.m.	376.5
23	8:15 p.m.	372.5	26	9 p.m.	374.5 (Pl. 12b)
24	9 a.m.	375.5	27	8 a.m.	376.5
24	11 p.m.	374.5	27	11 p.m.	377
			28	8 a.m.	376

January 22 was uneventful. The fumes were thick and the weather foggy in the morning; on rock fall was heard from the NE talus.

January 23 in the morning signs of sinking appeared. Activity was strong in the early morning, diminishing up to 8 a.m. Parting crusts appeared against the shores. An isthmus of skin separated the W pond from the pool, and stalactites grew increasingly bulky. Fumes appeared immediately on the bank at the W end, and streaming slackened.

At 1 a.m. on January 24 the pit was remarkably clear, the air still, and the dense fumes from the fumaroles W and N going straight up. The pool was low and somewhat enlarged in consequence of the caving in of the spatter rim about the peninsula.

On January 25 (Pl. 12a) from 8:30 a.m. until noon the pool remained nearly stationary, and a spatter rim formed along its shores. Sinking of 3 feet between noon and 1:30 p.m. was shown by the overhang of this rim and the stalactites below. A survey made during the afternoon showed enlargement of the lake since January 20, the rectilinear dimensions being 355 feet long, 187 feet wide on the E, and 125 feet wide on the W. The length following the curvature was about 440 feet.

In the evening January 26 (Pl. 12b) rocks were falling in the N talus. At 10 p.m. and thereafter a continuous thunderous thudding was noticed distinct from the noise of the fountains, but seeming to come from the pool. There were long stalactites in the caverns, and this rumble probably came from the cavernous space made by subsidence, under the platform, its roof being incessantly pounded by the surging fluid beneath and so thickening the cover downward by accretion. Subsidence went on until 11 p.m., but a slight rise at 8 a.m. January 27 was accompanied by almost complete cessation of the rumbling—*i.e.*, the cavernous space was full and incapable of resounding. The rising went on about 4 feet to 10 a.m. At 11 p.m. the pool had fallen back and was rumbling again, and Old Faithful was very noisy. On the morning of January 28 sinking appeared to have stopped during the night but to have recommenced, the stalactites in the caverns increasing in size between 7 and 8:30 a.m.

The accompanying photographs (Pl. 12) show the pool night and day from the Instrument House and at night from the E station. They show the streaming from W to E, the areas of fountains and blankets, the radial tearing blankets around the peninsula, stalactites in the caverns, the quiet inflow at the S cove, a blanket being sucked down into Old Faithful, and in one picture even the wall of the inner pit, at night, is shown.

Three earthquakes have been registered, two of which were exceedingly feeble.

On January 23 a shock was sufficiently strong to start the ordinary seismograph but not strong enough to write a satisfactory record on this instrument.

Jan. 27, from 2:33:35 p.m. to 2:34:34 p.m., H.S.T.

Intensity, low I, Cancani scale; distance of origin about 12½ miles.

Jan. 27, from 3:19:08 p.m. to 3:20:19 p.m., H.S.T.

Intensity, low I, Cancani scale; distance of origin about 19½ miles.

The "volcanic vibrations" have been strong during the week, with the usual irregularity in energy. Strong diurnal tilting occurred during the night of January 24–25.

WEEK ENDING FEB. 4, 1913

From January 28 to 31 the pool of Halemaumau rose 8 feet. It continued rising until the afternoon of February 1 and thereafter sank but slightly, maintaining on the whole a remarkably constant level for 3 days of about 363 feet below the N brink. The weather has been clear and sunny with only a little night fog. The wind has been mostly southerly.

The lava levels below the N rest house (3700-foot contour) have been:

Jan. 29 to 30 rising
Jan. 31, 2 p.m. 368 feet
Feb. 1, 12 m. 364.5 feet, 2 p.m. 361 feet, 8 p.m. 361 feet
Feb. 2, 10.30 p.m. 362.5 feet, 12 mdt 364.5 feet
Feb. 3, 7 a.m. 363 feet, 4 p.m. 363 feet
Feb. 4, 12 m 363.5 feet, 2:30 p.m. 365.5 feet

On January 31 the effects of the recent rise showed in an overflow bench around the pool; at noon February 1 evidence of a further rise of 4 feet appeared, and in the next 2 hours the lake rose 3½ feet. The spatter bench grew out some distance from the wall about the pool. A blowing noise could be heard from the caverns at the end of the S cove. Caves were fountaining tumultuously in the S and WSW coves. At 8 p.m. blankets had formed across the strait opposite the peninsula, and the surface streaming was E and W from these blankets as at the time of the high level of December 14. Overflows had taken place chiefly on the W side of the peninsula and at the E end of the lake—*i.e.*, on the E bank of each lobe of the pool. The major streaming is from W to E, the surface lava is cooler and piled up on the E banks, and the whole platform about the lake slopes down from W to E. This outer platform was formed by overflow in December. The new bench flows on February 1 were only 2 feet below the platform at the E end and about 10 feet below it on the W. When the blankets in the strait broke away the visible current through the strait from W to E was resumed. The finger cove at the extreme W end became crusted over, though a small blow hole opened in it February 2.

After very rapid rising to about 2 p.m. February 1, a subsidence began and continued with oscillations of level until midnight of February 2. At 10 p.m. February 2 long stalactites appeared in the caverns, and the narrow part of the pool opposite the peninsula crusted over and broke away. Surface streaming radiating out from the peninsula recalled December conditions. The caverns were very quiet, in contrast to the evening before. At 10:30 p.m. a rhythmic breathing noise, which lasted half an hour, was made by the blow hole in the western finger.

On February 3 a stationary condition of the pool was recorded by rounded lumps of spatter accumulation at many places about the pool. This rim was 3 feet high in places with overhang and stalactite formation.

Mr. Raymond Gaumont of the Gaumont Camera Co. in Paris spent the night of February 2–3 with the volcanologist at the Halemaumau camp. Between 7 and 10 a.m. a rope ladder was arranged to the bench 60 feet below the S station, remnant from the high level of 1912. At 11:30 a.m. Mr. Gaumont went down to the bench and arranged a second ladder to the talus, which he reached, walking out toward the SE fumaroles for 100 yards equipped with a rubber nose guard containing a wet sponge. The SE wind made an eddy that drew the fumes toward him so that he was forced to return and was unable to get moving-picture apparatus down to a favorable place.

Rumbling in the caverns was heard at 2 p.m. February 3 and at noon February 4. Soon after noon a splashing out of lava from the southern caverns and lessening of the rumble indicated the beginning of a rise. At 11 a.m. and 1 p.m. blanket isthmuses formed across the pool with accompanying changes in surface streaming. In each case the blankets soon broke up. At 2:50 p.m. February 4 the rumbling had ceased, the liquid lava in the S cavern was shooting out and up at 45° in splashes, and the noise was wholly that of splashing liquid without any rumbling. This was the beginning of a rise which continued to the next day.

The fumes have been dense during the day, sometimes obscuring the view, but generally there has been good seeing from the E side. The night views have been fine. There are flaming cones high up the W slope which have been brilliant. The densest fumes have come from the avalanche tumble of 2 weeks ago on the N inner slope.

The pool by survey February 1 at 3 p.m. was 325 feet long by 175 feet wide at the E and 150 feet wide at the W end. The narrowest part of the strait opposite the peninsula which juts out from the SW was 69 feet wide.

During the past week eight earthquakes have been recorded, one a teleseism imperfectly registered. All but one of the local shocks were very feeble.

Jan. 30, from 12:37:56 p.m. (noon) to 12:39:06 p.m., H.S.T.
  Intensity, low I, Cancani scale; distance of origin about 15 miles.
Jan. 31, from 12:43:00 p.m. (noon) to 12:55:02 p.m., H.S.T.
  The chief phase only of a teleseism moderate in energy at its origin.
  The distance and direction of the origin are indeterminate. Its energy at this station was very low in Grade I of the Cancani scale.
Feb. 1, from 11:33:15 a.m. to 11:34:19 a.m., H.S.T.
  Intensity, low I, Cancani scale; distance of origin indeterminate.
Feb. 4, from 5:19:49 p.m. to 5:21:06 p.m., H.S.T.
  Intensity, low I, Cancani scale; distance of origin 31 miles.
Feb. 5, from 1:59:57 a.m. to 2:00:42 a.m., H.S.T.
  Intensity, low I, Cancani scale; distance of origin 14 miles.
Feb. 5, from 7:49:01 a.m. to 7:50:57 a.m., H.S.T.
  Intensity, high I, Cancani scale; distance of origin about 30 miles.
Feb. 5, from 9:17:38 a.m. to 9:18:40 a.m., H.S.T.
  Intensity, low I, Cancani scale; distance of origin indeterminate.
Feb. 5, from 9:22:42 a.m. to 9:23:40 a.m., H.S.T.
  Intensity, low I, Cancani scale; distance of origin indeterminate.

WEEK ENDING FEB. 11, 1913

The lava column remains stationary at about the 363-foot mark. There have been fluctuations during the past week of as much as 6 feet in 4 hours. The record of changes of level has been as follows, measured in feet below the N rest house (3700-foot contour):

Feb. 5, between 5 and 9 p.m.; from 359.5 feet to 365.5 feet, sinking
Feb. 6, 10:45 p.m., 366.5 feet, has been overflowing, then sinking, now beginning to rise
Feb. 6, midnight, rising, and overflowing at E end
Feb. 7, very early morning, rising
Feb. 8, between 11 a.m. and 3:30 p.m., from 357.5 to 360.5 feet, sinking
Feb. 9, between 11 a.m. and 10:50 p.m., from 359.5 to 362 feet, sinking, but showing that some rising had occurred since the previous afternoon
Feb. 10, between 7:45 a.m. and 9 a.m. from 361 feet to 362.5 feet, sinking
  between 9 a.m. and 11 a.m. from 362.5 feet to 361.5 feet, rising
  between 9:40 p.m. and 10:40 p.m. from 361.5 to 363 feet, sinking
Feb. 11, between 6:40 a.m. and 7:40 a.m. from 362.5 to 360 feet, rising

As the last reading February 4 at 3 p.m. was 365.5 feet, the tidelike fluctuations were, in round numbers

Rise of 6 feet Tuesday afternoon to Wednesday afternoon, Feb. 4 to 5, 1913
Drop of 6 feet Wednesday evening
Strong rise to overflowing Thursday, probably 10 feet
Drop Thursday evening about 5 feet
Rise and overflowing early Friday morning
Drop Saturday during day 3 feet
Rise Saturday during day 3 feet
Rise Saturday night at least 1 foot
Drop Sunday of 2½ feet
Rise Sunday night at least 1 foot
Drop early Monday morning about 2 feet
Rise Monday morning after 9 of 1 foot and probably more
Drop Monday evening about 2 feet and probably more
Rise at least 3 feet Tuesday morning Feb. 11, 1913

From 4 to 9 p.m. February 5 the pool was very active, and until 6 p.m. it overflowed on the NE. The flows broke over the bank on the lower bench about opposite Old Faithful and streamed both ways back of the rampart and between the rampart and the low December wall. Activity was marked by rising in the middle, a blanket isthmus forming across the pool from the peninsula, and by surface streaming E and W from this isthmus, which after a time would break up and reform. A protuberant crust would build out from the N bank and meet a similar one extending from the peninsula. The baby fountain pattern was seen about Old Faithful. At 5:15 p.m. a steady hissing could be heard. At 6 p.m. a large blue flame was seen and photographed, spouting up through a crevice in the spatter rim on the N bank. A flow brimmed over the N rampart and spread E and SE along the NE bench at least 130 feet.

A survey on February 5 made the pool 319 feet long by 175 feet wide on the E and 150 feet wide on the W. The E end has been growing at the expense of the W, while the current up to this time had been from W to E, and by far the greater overflowing has been at the E end. On February 8 the pool was 320 feet long by 190 feet wide on the E and 140 feet wide on the W. The pool maintains the same "saddle-bags" shape which it has had since November, two lobes NW and SE about a peninsula which juts out from the SW.

At the south rim of Halemaumau, while survey was in progress, the notes of the past 4 days were blown over the cliff by the wind. The volcanologist went down to the 60-foot bench on the ladder and rescued the papers by using a long stick with a safety pin tacked on one end. The paper was 12 feet down the crevasse back of the bench.

Thursday and Friday, February 6 and 7, were culminating days for Halemaumau, when the lava column overflowed the E end of the December platform. Shepherd's cone was destroyed, and the low wall about the E end of the inner pit obliterated. The wall about the W end still surmounts the pool and the lower bench, and the December platform slopes down from W to E with reference to the level of the liquid pool. At the W end the wall appeared to be still 10 feet high on the night of February 6. Glowing edges of flows could be seen all about the E end of the floor, and at midnight cracks opened here and there, and small flows welled out. A cavernous opening, wide and low, appeared under the bank near Old Faithful at the NE corner of the lake. Fuming and flaming conelets on the bank had formed N, E, and S.

The inconsistency of the E side of the floor that surrounds the lake as a bench overflowing through Shepherd's cone, while a high wall persisted under this same bench at the W end of the lake, indicated that the bench lava was capable of rising high at the W from which direction came the principal streaming of the liquid lake. Numerous inconsistencies in measured vertical angles on different points around the lava lake had shown that both liquid lava and benches were changing elevation differently, in different places, and that the bench lava can rise, fall, and tilt independently of the liquid. Moreover, the liquid lava may be higher at one end (notably at the W) of the lake than at the other. As the surveying stations around the upper rim of Halemaumau were not all at the same level, and as even the sides of the seemingly solid rim of the pit might rise differentially, mere "depression below rim" was insufficient for precise measurement, and elevation above sea level, from fixed bench marks, must be determined.

By February 8 streaming had changed. It has been from W to E the whole length of the pool, but it began to radiate out from the SW peninsula and to flow E and W from the middle of the lake. On February 8 this became its regular habit, with inflow under the bank W, NE, and S, and very little inflow in the WSW cove.

Shepherd's cone was now overwhelmed by flows, which had run over the margin of the cup at the E end of the bottom, and the plane of the December platform sloped down from W to E.

February 9, after some sinking the flow under the WSW bank was resumed. On Monday, February 10, streaming from the middle to the W end became dominant again. The baby fountain pattern, which has characterized the W end since November, has diminished and is no longer distinctive of the W cove.

On the night of February 10 Old Faithful was noisy and violent and spraying over the bank, the dark blanket pattern characterized both halves of the lake with a few little spitting fountains, and New Faithful was still playing in the W pool.

During a sinking in the night of February 10, the end of the S cove exhibited a heavy layer of plastered lava at least 3 feet thick, its bottom edge flush with the liquid of the pool, and its upper limit built down from and against the stalactites of the previous day. In the telescope, sighting above the S cavern, these stalactites can be recognized, plastered over with the new layer of lava below. This tends to confirm the view that the pool builds a thickening crust above it as it sinks. Surface streaming on this night was pouring under the bank S and WSW, and the W end appeared dark and blanketed, but with some inflow. A high flaming hole in the NE talus appeared, nearly opposite Old Faithful. On the morning of February 11 there were very heavy stalactite masses beneath the plastered layer over the S cavern.

During the past week five feeble local earthquakes have been registered as follows:
Feb. 5, from 1:35:35 p.m. to 1:37:12 p.m., H.S.T.
Intensity, medium I, Cancani scale; origin distant 15.5 miles.
Feb. 5, from 4:11:36 p.m. to 4:12:47 p.m., H.S.T.
Intensity, low I, Cancani scale; origin distant 46.5 miles.
Feb. 6, from 10:34:10 a.m. to 10:35:06 a.m., H.S.T.
Intensity, low I, Cancani scale; distance of origin 12.5 miles.
Feb. 7, from 1:45:38 p.m. to 1:46:30 p.m., H.S.T.
Intensity, very low I, Cancani scale; distance of origin indeterminate.
Feb. 10, from 6:37:51 p.m. to 6:38:51 p.m., H.S.T.
Intensity, medium I, Cancani scale; origin distant 12.5 miles.
In addition two groups of "volcanic vibrations" have reached an intensity as great as local earthquakes, as follows:
Feb. 5, from 10:14:52 p.m. to 10:16:13 p.m., H.S.T.
Feb. 6, from 1:03:35 p.m. to 1:06:55 p.m., H.S.T.
The volcanic trembling has frequently been strong during the week. There has been nothing noteworthy about the registration of microseismic motion or slow tilting.

Week Ending Feb. 18, 1913

The week February 11 to 18 has produced a marked and spectacular change in the lake of lava. The peninsula has become an island. The change was followed by night and day photographs. The event was forecast in the report of January 21, 1913, when I wrote, "the sweep of the current around this peninsula suggests how the latter by further undermining might become an island". Last week I reported that surface streaming was pouring under the southern banks strongly on both sides of the peninsula and I thought the pool extended under the platform. This was confirmed when during the morning of February 17 the platform on that side of the peninsula caved in, left the latter an island, and was more consumed during the next 2 days, so that the lake changed from U shape to that of a ring around a central peak.

There have been no marked changes of level, as shown by the following measures of depth from the rim at the old rest house N of the pool to the surface of the liquid lava S:

Feb. 12 and 13, fumes obscured
13, pool about 1 foot below overflow rim of Feb. 6—365 feet.
14, 11:30 p.m., 362 feet
15, 9 a.m., 364 feet
15, 1:30 p.m., 362 feet
17, 7 p.m., 371 feet
17, 10 p.m., 368 feet
18, 7 a.m., fumes obscured
18, 6 p.m., 368 feet
18, 7 p.m., 369 feet
18, 9 p.m., 371 feet

This sinking aggregates 9 feet during the week, and the falling away of the peninsula to form an island was the beginning of a pronounced subsidence, but as before there have been fluctuations within a few hours averaging more than 3 feet a day.

The fumes have been increasingly baffling during the daytime with the resumption of strong NE winds, and both photography and observation are difficult.

February 12 and 13, there was no important change. An isthmus of blankets formed across the pool northward from the peninsula, with streaming E and W. This broke up and reformed. Small fountains and the blanket pattern were present in both halves of the lake.

February 14, streaming the length of the pool from W to E was resumed. There was a new surface stream out from the SE toward Old Faithful.

February 15, there was a small rim around the pool, and at noon the isthmus crust in breaking away on the W side swam to the middle of the W pool and there met a stream from the W which rode over and swamped the floating crust (Pl. 20c). A new flaming hole was noticed at the base of the avalanche tumble of January 21.

At 8 p.m. February 16 there was no marked change. The next afternoon the peninsula was replaced by a high island surmounted with three pinnacles, the latter glistening with black pahoehoe lava. Apparently the mass of the peninsula broke away from the SW shore, probably along an upright crack, and a great spall of the side and bottom of the pool sagged out into the lake, lifting its summit portion, tilting it, and by some unexplained mechanism plastering it with lava flows. The process was probably similar to that which made Perret's islands of 1910–1911 (1913).

There was a crusted strait between the island and the SW shore. This shore widened out on February 17 and 18. A flaming cone formed on the NE bench near the pool. The streaming continued to pour E and W from the island and strait as it had done with the peninsula. At 7:30 p.m. February 17 an east-flowing current broke through the S strait for an instant only. The next day this had become its regular habit. Old Faithful was very active, and there was violent inrush and downsucking S of it.

At 7 a.m., February 18, the pool was sluggish and rumbling. In the late afternoon the activity of fountains was greater than of late. The lake had become annular around a small glistening pinnacled black island, with streaming eastward both N and S of the island, and there was a rapid acceleration of current into the vortex S of Old Faithful. The western end of the pool was pointed, the eastern rounded, and blankets tended to form across the lake northward from the island.

The Director will make brief seismologic notes during the next few weeks in the absence of Mr. Wood. The small Omori tromometer pendulums were hung February 11 at the Halemaumau station.

February 12 and 13, there was much tilting, as shown by the major tromometer at the Observatory. February 13, the volcanic tremor was strong, and 4 local earthquakes were recorded at 6:19 a.m., 10:49 a.m., 10:56 a.m., and 11:01 a.m., respectively. Of these the third was strong enough to start the ordinary seismograph.

February 15 to 17, tilting was not pronounced. One weak local earthquake was recorded at 7:42 a.m., February 16.

February 18, tilting began again, becoming very strong, particularly toward the E, on the following 2 days.

WEEK ENDING FEB. 25, 1913

In the past week the lava column has fallen 87 feet, with streamings from the W end to the E end amounting to cataracts at times, and leaving the W pool 15 to 20 feet higher than the E pool, into which it pours its glowing overflow. There have been avalanchings and changes of shape and size of the lake, which first enlarged and then shrank. Activity of fountains has varied, and there have been temporary risings. The fumes have increased in volume, and immense fume holes have developed in the slide rock.

Recorded levels below the rim have been:

		Feet
Feb. 19, 3 p.m.,	below SW station	388 to E pool
21, 2 a.m.,	below Instrument House	390
21, 7 p.m.,	below E station,	410
22, 5 p.m.,	below SW station,	424
23, 9 p.m.,	below Instrument House	434
24, 8 p.m.,	below E station,	435
25, 8 a.m.,	below Instrument House	458

On the evening of February 24 the lake by survey was 328 feet long by 167 feet wide. There was a peninsula against the S shore, within a few days an island, 65 feet wide, and an outlying islet separated from the peninsula by a torrent. This islet was 50 feet long. The lake was an irregular oval pointed at the W end.

At 6 p.m., February 19, the two vapor jets high on the NE flank of Mauna Loa were seen for the first time in many weeks.

February 19, the island in Halemaumau was pinnacled, there was inrush of lava under its E end, and a line of downsucking S of Old Faithful. Eastward streaming S of the island was becoming slow.

On the night of February 20 there were many rock falls, the great W chimney was enlarging into a resounding chasm where rocks were engulfed, rocks repeatedly fell into the elongating W finger of the pool, and the NE and S corners of the lake were becoming angular and enlarged.

February 21, the pool passed through a rising stage which covered all but the W pinnacle of the island, and then it sank again leaving the island flat-topped. The SW fumarole high in the slide rock had opened a 3-foot circular hole from which cauliflower clouds of semitransparent vapor gushed rapidly under pressure, condensing to dense blue and brown smoke. The island became joined to the S shore.

February 22, the S fumarole had opened a great hollow below the E A-frame, and rocks were incessantly tumbling into it during the afternoon. The SW hole was also greatly enlarged and caving in.

In the evening of February 23 the rock falls were almost continuous. The peninsula, lately an island, was large and high and banked with crusts N and W. The lake was rumbling in caverns.

After 9 p.m. the view from the north Instrument House indicated such profound subsidence within the inner cup that much of the lake was concealed from view by the inner cliff.

February 24, the inner platform sank and caved, and the large S fumarole was full of stones. In the morning the lake was sluggish and blanketed, but in the evening the peninsula was broken through in the midst by a torrent pouring from W to E, making of its northern extremity an island, and N of this again a river of melt swept from the western pool into Old Faithful, past the mouth of the narrower stream S of it, and carrying boats of crust from the W pool to the E. The fanning and festooning mechanism of the smaller stream was wonderfully beautiful in its geometrical pattern and kaleidoscopic in its changes. Evidently the W pool was much higher than the E.

The next morning, February 25, the lake had fallen 26 feet, the small stream between the peninsula and the island was a quick chute, and the E pool had developed an unusual northward streaming in the Old Faithful region. The peninsula was mainly an isolated high roundish cake with a flat top, and overhanging below. Immense stalactites overhung the S shore of the western pool.

There have been two local earthquakes recorded by the ordinary seismograph, 6 p.m. on February 20 and about midday February 23, time unrecorded. A remarkable tilt of the ground to the E took place, gradually increasing between February 18 and 22; February 22, the writing needle of the large tromometer was off the drum all day. February 23, a fairly strong earthquake started the ordinary seismograph at about the time when this tilt reached its maximum. From February 23 to 25 the writing needle returned to its normal position and is now recording no unusual tilt, and the microseisms and volcanic tremors are very weak.

The seismologic record of the week shows that tilt and volcanic tremor at the observatory, near the Volcano House, have in some sense kept pace with the happenings at the lava pit. Tremor was very strong during the sudden fall of February 25–26, especially between 9 and 10 p.m. February 25. At 1:45 a.m. February 27 a feeble earthquake occurred. After February 28 stronger tilting to the E began, alternating with a daily recovery by tilt westward, and the dominant eastward tilt increased during the next 4 days and culminated March 3–4 when the pen swung clear of the drum on the large tromometer and ceased recording. The following day it returned to its position, repeating the phenomenon observed February 18 to 22. Subsidence of the lava, as before, was dominant during the time of excessive tilt. On March 3 just after the high lava level of the week (412 feet) two local earthquakes occurred at 4:09 a.m. and 5:21 a.m. Both showed a sudden offset of the pendulum to the E accordant with the eastward tilt. Tilt and volcanic tremor both became weaker March 4–5.

The minor Omori tromometer has been started at the Halemaumau Station and records local tilt and small jars made by the avalanches at the pit. It is now in process of tuning.

Water Vapor and Fume:

Throughout 1912 it became clear that when the lava went down the "smoke" within Halemaumau became denser and obscured the view. When the lava rose and developed visible incandescent fountains, grottoes, bright lines, and spouting border cones, the fume became thinner, and the seeing of the spectacle was clear. The observers learned to distinguish white vapor from blue fume. A hot vent achieving incandescence or spouting lava gives off blue fume. The lava fountains emit blue or brown fumes. The cracks in border benches, and around the edges of Halemaumau itself, give off white vapor which is mostly water vapor. When the lava lowers, the tubular conduits of all the vents become condensation chambers. Just as in vacuum tube collections, the slightest chilling produces condensation of water vapor. When the whole pit filled with vapor in a singularly dense column in the summer of 1913, although the live lava was generally present at a depth of about 600 feet below the Halemaumau rim, this condensing mechanism was at its maximum. The daily photograph gave a record of this for several years (Pl. 8).

The year 1913 was the low-level year between two 11-year cycles, and the pit was full of vapor. The year 1924–1925, when the lava surface was about 1200 feet down, there was no tendency whatever for the pit to fill with fume or vapor; it was always clear, in spite of the fact that a steam blast had characterized the 1924 eruption, and thousands of tails of steam had covered the talus when that eruption ended (Pl. 51e). Nevertheless, this steam showed no tendency to collect in convectionally rising billows that would fill the pit, as did the vapor of 1913 (Pl. 50). There would seem to have been a more effective condensing chamber in 1913 than in 1924. The difference is not yet satisfactorily explained.

The remarkable rising and falling of this 1913 period, apparently occasioned by the liquid lava becoming confined within a narrow funnel of bench magma, led to the extraordinary spiral whirlpool at the site of Old Faithful on the night of February 27 (Pl. 11). These whirlpools have been seen on several occasions since 1913 and were reported in the nineteenth century. They are produced when the sink-hole wells of the convectional circulation of liquid lava become dominant, and the feeding shafts at the W side of the pit bottom become sluggish. There results a shallowing of the lake saucer, and, if the surface circulation of streaming from W to E makes a tangential jet against the margin of the sink-hole funnel, a whirlpool is set up. At night the crusts and skins and minor fountains delineate the pattern of the whirlpool, and what was a slower streaming with rhythmic fountains on the high-level lake becomes a torrent across the floor to end in a spiral cascade. Possibly the marked vapor column of Halemaumau in 1913 was due to the presence of the many tubes in the bench magma cylinder, within which hydrogen and other gases were burning; whereas in 1924 the enormous collapse that filled the void with broken rock so cooled off the lava column that recovered that no such tube system formed to make a combustion chamber. Each eruption after 1924 was started by gigantic fountains up the wall crack (Pls. 33, 55, 57), and enormous volumes of gas suddenly released and quickly expended. Doubtless these gushes at the beginning of each outbreak take the place of the continuous expenditure of combustion products that was going on in 1913.

Tilting of the Ground:

The seismologic record of this week describes strong tilting to the E as measured in the seismographic cellar on the NE rim of the greater crater. Eastward tilt is away from Mauna Loa, and northeastward tilt is away from Halemaumau. During two spells of several days this tilt to the E happened during subsidences of the lava. Both these spells culminated in local earthquakes, and in one of them eastward tilt accompanied the earthquakes. In both cases the lava column turned and started to rise after the spell of tilting. Such changes of tilting of the ground stimulated the Observatory staff to make arrangements so that the amount of tilting could be measured in seconds. Later this was done with special instruments at three cellars around Halemaumau pit (Volcano Letter No. 434). Tilt curves have shown that unusual tiltings away from the greater crater tend to forecast a rise of lava more than a fortnight in advance. At Halemaumau itself immediate response to the onset of uprising has been observed within a few minutes or hours. Thus, tilt measurements at an active crater may be indicators of internal tumefaction (Volcano Letter No. 467).

WEEK ENDING MAR. 4, 1913

The following has been the record of lava level below rim in Halemaumau for the past week:

			Feet
Feb. 25,	8 a.m.	below Instrument House	458
26,	6:20 p.m.	below Instrument House	500
26,	7:30 p.m.	below Instrument House	459
28,	11 p.m.	E Station	472 (Pl. 11b)
Mar. 1,	7:35 p.m.	SE Station	426
2,	6 p.m.	S Station	412
3,	9:15 a.m.	S Station	439
4,	7:15 p.m.	S Station	446

The fumes so increased from many vents high and low during the week that surveys became impossible in the daytime, and vertical angles were mostly measured at night with clinometer compass on the basis of the survey of February 24. Accordingly these depths are only approximate, but they show unusual fluctuations per day in height of the lava column, more than 40 feet being recorded three times. The second of these, February 26, was a rise of 41 feet in 1 hour and 10 minutes and was accurately measured with alidade and spirit level. As the column becomes confined within a narrow funnel and so diminishes in surface area, risings and fallings seem to be more rapid.

February 26, at 6 p.m. the rapid fall of the lava column showed from the N in that the lake was concealed beneath the cliff of the platform of last December. From the SE the E and W pools could be seen; a torrent poured down a slope between the two from W to E. There was a standing wave or rapid in the middle of the cascade, and blocks of crust and skin swept down on the surface of the stream from the W pool, to be engulfed in the maelstrom of Old Faithful. New Faithful has been persistently active lately near the S margin of the W pool. Falls of talus could be heard, but a sudden rise of over 40 feet caused the E pool, between 6 and 8 p.m., to brim over its spatter border, and the noise of rock tumbles ceased.

At 1 a.m. February 28 the lake appeared narrower, small fountains were playing in the W pool, and heavy falls of rock were heard toward the W. The rapid torrent still poured into the E pool, which overlapped the chute of glowing liquid with a mantle of eddying viscous cooler lava, and this surface mantle initiated a new stream in the same line with the chute which curved and reached Old Faithful in a remarkable spiral whirl (Pl. 11b). The two islets of recent times together make a south peninsula once more. Glowing cones have developed on the SW, E, and N benches at various levels.

On the evening of February 28 the lake was lower, the spiral vortex had ceased to play, the surface blankets were sluggish, and small ponds in a hard crust appeared in the W pool. At 10 p.m. from the E a narrow stream still poured from the W pool to the eastern pool, the activity elsewhere was slow, and rock avalanches fell into the liquid lava from the wall of the inner pit W and S. Tumbles in the higher talus were heard W and SW. The fumes from many vents made seeing difficult.

March 1, a very pronounced rise ended the torrent pouring from W to E, and its site crusted over, dividing the lake in two. In the E pool the streaming was from W and S into Old Faithful. In the W pool it was from E and W, pouring under the banks N and S. Stalactites hung under the bank at the N side of the W pool and at its S end was a boiling pot in the crust.

On the evening of March 2 streaming from the N and S banks of the E pool coalesced in downrush at Old Faithful. Two heavy avalanches during the evening shook the high rim of Halemaumau. The next morning a portion of the bench 60 feet down on the S side of the crater had fallen, undermined by solfataras. The rise of March 2 had caused overflows from the eastern glowing cone, making a slope down to the lake in place of the platform and cliff. The pools were again sinking, and the talus everywhere sliding.

There was a large crack in the rim above the place where the S bench had fallen, and the W end of this bench sagged outward with a crevasse between it and the wall. This was the bench to which we had descended with rope ladders (Pl. 3f). The SW fumarole was full of fallen stones. The ledge 200 feet down had caved.

The night of March 4 revealed irregular sluggish streaming in the W pool, whereas in the E pool the streaming was rapid, from S and NW, toward Old Faithful. The latter broke in triple and quadruple domes. Downsucking appeared to be taking place at both Old Faithful and New Faithful. A filagree cone, glowing within, had formed W of the peninsula, on the bank. Farther W a sheet of flame was playing from a large hole. Two glowing cracks surmounted the eastern cone. Occasionally Old Faithful exploded directly over the bank W of the E pool, causing it to cave under bombardment and so enlarge the pool. This bank was the N side of the peninsula. One glow hole SW of the W pool appeared to be at least 60 feet above the lake and to have lava splashing within it.

Lava Cascade into Well:

This was a remarkable week, of temporary boiling upward of the liquid lava so as to convert the peninsula again into islands. Some experiments with photography on panchromatic plates demonstrated that the motion of the liquid lava in fountains at night could be delineated instataneously on such plates. The remarkable cascade from the lake, into a well at the lake shore, pouring over a submerged sill as a cataract (Pl. 44c), showed that the lake bottom behaves as a ledge. This was one of the early manifestations of the fact that the liquid lava is underlain by its own congealed substance, just as it is confined by margins of that substance. Its cooling proceeds from below upward, as well as from the sides inward, and only the hot gas action maintains wells in the mobile but stiff bench magma.

WEEK ENDING MAR. 11, 1913

The lava pool of Kilauea during the past week has become a magnificent spectacle. The fumes have diminished. The records of fluctuation in level have been as follows, in depths below the rim:

			Feet
March 8,	4 p.m.	below NW Station	468
9,	6 p.m.	S Station	438
10,	7 a.m.	Instr. House	446 (Pl. 11c)
11,	7 a.m.	Instr. House	434

The lava column has risen slightly. The fluctuations in activity have been, as before, an adjustment of level between a higher W pool and a lower E pool. A marked change began March 8, when the two sluggish pools of the preceding time of depression began to resume activity, closely comparable to that recorded about February 18 and thereafter, the peninsula again becoming an island and rivers of lava pouring from the W pool to the E. The rise and fall of the liquid was so rapid that in one night the island was totally submerged and reappeared.

March 5 to 7, conditions remained about stationary, there were two pools, activity was slow, and fumes prevented good seeing. March 8 in the afternoon the western pool had been hissing from crusted openings, New Faithful was a low cone in crust with a pot where the fountain boiled, and the peninsula was supplemented by crusts which formed a broad bridge separating the two pools. About 4 p.m. flows welled up through cracks in the western crusts, and a flow swept in festoons along the N side of the bridge eastward, connecting the western pool again with the eastern. Another flow began to pour from New Faithful SE over the isthmus of crust which there separated the high part of the peninsula from the S bank.

March 9, a river of lava was pouring again from the W pool to the E. At 8 p.m. the peninsula had become two islands, then one, and at 9:30 this island was submerged, and the streaming had become slower and more diffused. Blanket patterns spread over the lake. In 24 hours it had changed from two pools to the "saddle-bag" shape, then to a ring about the islands, and now it was pear-shaped with the stem to the W.

At 2 a.m., March 10, the island emerged again, and rapid sinking for a few hours restored the small islet and two rapid streams flowing from W to E. At 7 a.m. an amazing structure there was a nichelike cove or vertical groove in the WSW wall, *into* which the liquid lava of the lake poured over a submerged sill like a cataract. It poured into a well within which lava could be seen boiling *a few feet below the level of the lake.* What could make the sill is an unanswered question. This cascade flowing into the wall recalled the similar torrent which cascaded in 1911 under Perret's island (Pl. 11c).

After 8 a.m., March 10, the pool rose rapidly, and the smaller islet was again submerged. Conditions then became relatively stationary. There was one flat-topped heart-shaped island about 2 feet high. East of this violent boiling in a E–W line had developed. Toward this place the E-flowing currents converged, and there the blankets were sucked down. There were many overflows about the rim, and there was bombardment of the shore at points WSW, N, and NE of the lake, and against the SE corner of the island.

Measurements of the early morning show a lowering of 31 feet between 7:15 and 7:30 a.m., between the E tip of the island and the middle of the W pool. The cascade poured into the wall on the S side of the W pool. The lake at 10:30 p.m. (Pl. 11d) was much the same as at 9:00 a.m., with E-flowing streams on the surface both N and S of the island, a line of downsucking fountains E of the island, overflows of the bench around the rim of the lake, and inrush to the bank at four places. The only outflow from the bank was at the W end. The rhythmic fountains were weak, and fumes were thinner.

March 11, the fumes greatly diminished.

Seven local earthquakes during the week made the seismograph record. These were at the following approximate times:

9 a.m. March 6
2:31 a.m. March 7
11:34 p.m. March 8
8:55 a.m. March 9
5:01 a.m. March 10
7:37 p.m. March 10
2:16 a.m. March 11

Those of March 9 and 11 were strong enough to start the ordinary seismograph. The tilting has this week been moderate. Volcanic tremor and microseisms were both strong during the rapid rise of the lava March 8 to 9.

Week Ending Mar. 18, 1913

The high level of the rising period was passed about March 12, when the fumes were notably thin. March 13, the fumes greatly increased, and sinking of the lava from 400 feet down or less began, reaching the following levels on successive days:

			Feet
March 14,	7 p.m.	below N Instrument House to W pool	430
15,	9 p.m.	" " " " " "	447
16,	10 p.m.	" " " " " "	441
17,	6 a.m.	" " " " " "	454
18,	6 p.m.	" SE Station " "	452

On March 13 crust joined the island to the S shore. March 14, the western pool was much crusted, two pots in the crust were boiling against the SW wall, fumes were heavy from S and W vents, and there were overflows and glowing rims E and SE in the afternoon. A rapid stream was pouring past the N bank of the island from the western pool to the eastern one. The cascade flowing into the wall appeared as a quick insucked flow toward the wall in the easternmost of the two SW pots. From 5 to 7 p.m. this flow appeared to be of very rapid streaming as though of extreme liquidity. The W end was blanketed, with surface streaming in the western pool to the N and E. Rumbling increased, different from the pure splashing noise of the afternoon, when the pools had been rising; the change marked a transition to subsidence. With the sinking, New Faithful became very noisy. At 9 p.m. the activity was stronger, and Old Faithful was breaking in multiple fountains.

The lake by survey 8 to 9 a.m. March 15 was 325 feet long, with a rim of overflow E which would add 30 or 40 feet to the length of the inner caldron. It was 140 feet wide at the W and 150 feet wide at the E. The torrent from the W pool was 45 feet wide at its narrowest part. The island was 19 feet high.

Activity decreased March 15, and the E pool was 10 feet lower than the W pool. The torrent between the pools was swift and sloping.

March 16, Halemaumau remained stationary, and the pot which had shown inrush toward the wall became crusted over and invisible. Rare talus slides were heard.

March 17 the western pot against the SW wall showed rapid insucking. The north strait where the torrent had been became crusted over. The long-continued cascading from the lake into the western pot showed that these cascades into a well are part of the general circulation of the liquid lava, usually concealed when the liquid is relatively high.

March 18, there were two pools, the straits N and S of the island were solid crusts, but the streaming poured into the eastern pool still from under the crust of the northern strait. Old Faithful was exploding in enormous single domes against a high NE bank. The N talus, where an avalanche was occasioned by solfataric undermining January 21, 1913, was tumbling again and threatening the security of the 1912 bench at the 60-foot level under the old N rest house. Gaping cracks back of this bench have lately widened.

The seismograph has shown one powerful distant shock 10:30 p.m., March 13, which wrote its record for an hour. A local weak shock was recorded 6:18 a.m., March 14. From March 14 to March 18 there has been daily tilting and increasing amplitude of microseisms.

The Blow-Pipe Effect:

Discussion of fusing of talus fragments engulfed by lateral incandescent fumaroles is here a continuation of what has been mentioned before, the "champagne cork" effect. There is no question but that the burning of hydrogen and other gases confined in a blow pipe of lava glass can produce a Bessemer-furnace effect amid loose material. Alternations of rising and sinking lava, with collapse of the wall margins and increasing confinement of the burning gas, furnish the conditions necessary for alternation of quenching by infall and recovery by gas melting. This is helped by the large quantities of iron oxides to act as catalyst and as source of oxygen along with the air carried down into the liquid lava by the sinking of vesicular fragments (Pl. 6).

WEEK ENDING MAR. 25, 1913

The N high bench, 60 feet below the old rest house (Pl. 3b), left by the high lake of January 1910 and again splashed by the high lava of December–January 1911–1912, has fallen. Persistent remnants of these high-level benches have clung to the walls of the pit N, S, and NE. The NE locality is under the E station and has not been recently disturbed; it is supported by the E end of the large 1894 bench which it overlaps. The N bench started to fall at its E end January 21. The S bench became deeply notched by avalanching March 2. Now the N bench is almost totally destroyed, and the S one has crumbled back to the wall leaving two remnants on either side.

In general a slow sinking of the lava has accompanied this tumbling of the high inner slopes, but the subsidence has been small. The surface of the E pool below the rim has been approximately:

				Feet
March 19, 7 p.m.	Below	N	Station	435
20, 8 a.m.	“	“	“	450
21, 6:30 a.m.	“	S	“	460
23, 6 p.m.	“	N	“	456
24, 7:30 p.m.	“	S	“	470

In the evening of March 19 the pool appeared active with a strong glow, many small fountains E, the plashing noise without rumble characteristic of a rising phase, and Old Faithful fountaining in multiple domes. Some rock falls were heard at the N.

At 8:10 a.m., March 20, a great brown cauliflower cloud rose from the N rim of Halemaumau and was seen from the Volcano House. Mr. D. Lycurgus was on the rim and heard and saw a large portion of the E end of the N bench fall. The major tromometer at the Observatory recorded a strong volcanic tremor, and the ground tilted W.

March 21, in the evening the E end of the N bench had tumbled so as to sever all connection between that bench and the shelf of 1894. There was no great change in the two pools. The island had become a wide isthmus. There was a cavern with stalactites at the N end of the eastern pool. The western pool was rather stagnant, and the fumes were very heavy. New Faithful was exploding under a bank sometimes throwing up spatter. High above the S end of the western pool was a broad crack trending E-W emitting a very large sheet of flame. The streaming of the eastern pool was toward Old Faithful from the W and S.

The pit was an immense cylindrical cavity with the talus sinking. Apparently during the past 6 months the lava has been consuming the great quantity of waste from sunken benches which has slowly subsided into it since the high level of January 1912. This consumption proceeds partly around the visible edges of the lake but also in large measure in many peripheral cracks filled with lava below and fuming above. The lava below undermines these cracks, often opening them into small craterlets and cones, revealing the deep glow and engulfing many tons of slide rock. This fusing of slide rock by lateral fumaroles is a form of activity of the pit of great effectiveness; it alternates with a rising pool with many fountains, the rhythm of alternation being controlled by the conflict between the heat supply and the chill of increased downslipping of talus into the funnel. Peripheral activity has been dominant during the past week, and the upper benches have been engulfed. Whether the unusual seismic activity of the week is cause or effect in its relation to the performance of the volcano is a question for theoretic interpretation.

March 22, the low level was evidenced by much flaring at night occasioned by the explosions of Old Faithful illumining the fume cloud, otherwise dull red; heavy rock falls took place, especially from the N side. The next day the whole W end of the north bench was gone, immediately under the Instrument House, except a strip about 2 feet wide next to the wall. The remainder had subsided to a cracked craggy group of flat-topped pinnacles, with dust rising from many small slips. The NE cavern in the lake had disappeared; otherwise there was no perceptible change on March 24. The S bench had broken back to the wall behind it, and the remnant of the N bench was still smaller and lower. At 6 a.m., March 25, there was a gentle rattle of sliding stones on the N talus, the remnant of the bench continuously crumbling. There were also rock falls at the S. The pools were noisy and active. The flat-topped eminence which had been the island, between the pools, was high and fuming.

On March 24 between 4 and 5 p.m. a series of temperature measurements were made with mercurial thermometer containing compressed CO_2, reading to 500°C, made by Green of Brooklyn. Temperature of the air was 19°C. The place measured was the postal-card crack (Pl. 9b) starting at its E end and approaching the white solfataric area where blue-brown fumes emerge from the excessively hot part. This is a solfatara 200 feet N of Halemaumau. The crack is 2 to 6 inches wide. The thermometer was exposed 10 to 20 minutes for each measurement. The readings varied from 25° through 38°, 53°, 58°, 220°, 145°, 285°, up to 303°.

Continuing this work March 25 at the W end of the postal-card crack, temperature of air 23°C, temperatures were read of 30°, 40°, 60°, 70°, 90°, 110°, 158°, 290°, and finally 323° 12 inches down the crack, obtained by exposing the thermometer 25 minutes. The end of a pine rod used to support the thermometer was transformed to charcoal. The thermometer reached 260° rapidly; it took 5 minutes more to reach 300°, then 10 minutes to reach 320°, and 10 minutes more to reach the maximum 323°. It was later found advisable to encase the thermometer in iron pipe. Thin blue fumes rose at the hottest places.

The following 15 seismic disturbances have been registered at the Observatory.
March 17, from 1:24:57 p.m. to 1:25:26 p.m., H.S.T.
Intensity, low I, Cancani scale; origin distant 16 miles.
March 19, from 8:30:06 a.m. to 8:31:15 a.m., H.S.T.
Intensity, medium I, Cancani scale; origin distant 23 miles.
March 19, from 3:17:58 p.m. to 3:19:37 p.m., H.S.T.
Intensity, medium high I, Cancani scale; origin distant 22 miles.
March 21, from 8:02:48 p.m. to 8:03.5 p.m., H.S.T.
Intensity, extremely low I, Cancani scale.
March 22, from 1:55:55 a.m. to 1:56:46 a.m., H.S.T.
Intensity, low I, Cancani scale.
March 24, from 3:24:51 a.m. to 3:25:51 a.m., H.S.T.
Intensity, medium I, Cancani scale; origin distant 15.5 miles.
March 24, from 9:06:53 a.m. to 9·08·01 a.m., H.S.T.
Intensity, very low I, Cancani scale;

Now began a series of shocks, in rapid succession, quite without precedent in the experience of this Observatory. None was felt here, though at least one should have been perceptible. A strong wind was blowing in gusts producing frequent shiverings of all buildings, and the shock probably passed unnoticed. In Hilo tremors were reported perceptible for about 10 consecutive minutes. Continuous vibration, though far too feeble to be perceptible, was registered for several minutes at the edge of the main crater. Nearly all these shocks originated approximately 20 miles away, presumably in the Hilo direction.

March 25, from 10:36:22 p.m. to 10:37:04 p.m., H.S.T.
Intensity, very low I, Cancani scale.
March 25, from 10:49:52 p.m. to 10:51:41 p.m., H.S.T.
Intensity, low I, Cancani scale; origin distant 22 miles.
March 25, from 10:51:41 p.m. to 10:53:40 p.m., H.S.T.
Intensity, high III, Cancani scale; origin distant 20 miles.
March 25, from 10:57:29 p.m. to 11:00:42 p.m., H.S.T.
Intensity, IV-V, Cancani scale; origin distant 22 miles.
March 25, from 11:00:42 p.m. to 11:04:21 p.m., H.S.T.
Intensity, medium I, Cancani scale; origin distant 22 miles.
March 25, from 11:04:21 p.m. to 11:06:36 p.m., H.S.T.
Intensity, medium-high I, Cancani scale; origin distant 25 miles.
March 25, from 11:06:36 p.m. to 11:07:53 p.m., H.S.T.
Intensity, medium I, Cancani scale; origin distant 25 miles.
March 25, from 11:24:54 p.m. to 11:26:17 p.m., H.S.T.
Intensity, medium III, Cancani scale; origin distant 25 miles.

During the last 3 days there has been pronounced eastward tilting, gradually increasing microseismic waves, and, sporadically, strong volcanic vibrations.

Avalanches and Hot Rim Cracks:

The great number of avalanches and the slipping down of marginal benches that increased as the top of the lava column lowered beyond 500 feet raises theoretical questions about the cross section of the perilith—the border rock of a pit in depth. Well-known Hawaiian pits such as the "Devil's Throat" are cupola-shaped, larger below and smaller above to depths of 250 feet almost perfectly circular, and left by lava receding. Halemaumau, however, is funnel-shaped. The dynamical theory of cone fractures developed by E. M. Anderson (Bailey, 1924) presupposes an upward pressure of magma at a point deep under a horizontal surface of rock, developing a pressure system in the crust and creating shells of compression upward, yielded to by superimposed tensions, making cup-shaped opening fractures. These cup-shaped fractures make the familiar rim cracks around the pit cup, becoming concentric benches that slip downward and inward when the pressure of magma is withdrawn. If intrusion fills such fractures, there would result annular cone sheets dipping toward the center. When the conditions are reversed and the magma sinks, the downward pressure of the concentric crust tends to create tensions that result in concentric fracture that in section dips outward, cuts across the former cup-shaped fractures, and develops infall of blocks toward the center about a bell-shaped opening larger below. This may be paraphrased by saying that the pit is a cup-break over central upward pressure, and collapse is a bell-break under central downward withdrawal. The assumption in both cases is of domical magma reservoir, or a rounded vertical pencil pushing upward or receding.

The assumption of a dome-shaped pencil of magma as a center for radial dikes or concentric intrusion is justified under a circular crater if the edifice is circular. The presence of circularity means concentration in the course of vertical upflow by marginal congelation during upbuilding. A dike below becomes a circular well, by sealing off the longitudinal extensions. The edifice then becomes a circular dome, with a circular well in its center. If by congealing at the top and sides a form of equilibrium due to cooling is left for the inner viscous lava column, that form would naturally be a dome-shaped pencil. This means that deep under a pit over receding lava the perilith must show overhang in cross section.

Anderson's stress diagram therefore becomes of fundamental importance in discussing the avalanches and the inward slipping benches of Halemaumau when the lava goes down. The upper walls of the pit slope inward toward the center. When the benches slide down, they slip inward toward the center. This shape and these sliding surfaces are the cup fractures created by the earlier upward tension. When the bottom of the pit enlarges, the implication is that the marginal cliffs are being undermined at their bases, that fractures are widening back from the edge of the pit, and that the overhang below the visible bottom region is causing collapse. The opposite walls of the cup must then tend to approach upward, the steepening of the cliffs causes debris to fall, and what had been tumefaction becomes shrinkage, and the vent somewhere in cross section may be conceived to have hour-glass form.

The hot steam vent called the Postal-Card Crack or Pele's kitchen, here described as yielding temperatures about 320° C, is on a series of concentric vertical cracks around Halemaumau about 200 feet from the edge of the pit. This fissure yields hot sulphur gases and steam (Pl. 9). Its development was not wholly due to tumescent tensions. This ring of cracks was the trace of the old pit margin of 1894. In that year the inner lava lake built up an inner dome of overflow to the point of burial of this outer edge, and then sudden subsidence lowered the lava in the inner lake funnel only, and that funnel was the smaller pit of the next 20 years. Thus the postal-card crack (where tourists burned postal cards) was the wall crack of the larger pit of the years preceding 1894. It showed no changes of temperature when lava rose and fell in Halemaumau. It was always excessively hot, but not glowing. In 1919 it emitted the lava of a dike rising through it when the Halemaumau lava lakes came up to the top (Pl. 30). Then only did its temperature change to the incandescence of flowing lava.

WEEK ENDING APRIL 1, 1913

During the week the inner pit was increasingly obscured by fumes, with the liquid pools of lava crusted, and the gases confined so that hissing and puffing have become the dominant noises. The volcano is as it was last September, which was also the time of equinox. The lava column has subsided to a level over 500 feet below the rim. Clear seeing is rare.

The measurements of the week have been:

			Feet
March 27,	9:30 p.m.,	Below N. Instrument House to E Pool	479
28,		sinking as shown by many avalanches	
29,	9:15 a.m.,	Below SE Station to E pool	516
29,	11:30 a.m.,	" S " " " "	522

On the evening of March 26 there were two pools, the E with Old Faithful for principal fountain, the W with New Faithful. There was some increased activity, and talus slides were numerous especially on the N. March 27 from 5 to 8 p.m. the fumes appeared thinner, and there was some seeing of the bottom area of Halemaumau even by daylight. Talus was sliding N, S, and W. The last remnant of the N bench fell with a crash at 8:01 p.m. The crusts broke up, and both pools glowed with unusual brilliancy after the fall; Old Faithful boiled high and filled temporarily the whole N end of the E pool.

A crusted southern channel around the S side of the former island was seen during a clear spell, and the main stream under the crust from the W pool to the E appeared to be following this channel, to judge from the streaming surface current in the E pool. A high-walled inner pit with crumbling edges enclosed the area containing the two pools and the central eminence which had been an island.

March 28, avalanches were numerous, and at times the sliding noises were incessant. The E *pool at 8:30 p.m. narrowed to a N-S fissure with Old Faithful at its northern end, so confined as to* rock the whole pool with its explosions. The W pool showed increased activity. There were five distinct benches in the tumble of debris between the S wall of Halemaumau and the pools. The western remnant of the highest bench showed a gaping crevasse 2 feet wide between it and the wall at 9 a.m. At 6 p.m. this fissure was 4 feet wide. It was hence expectable that this bench would fall soon.

A survey, unsatisfactory because of fumes, was made during the morning of March 29. The E pool was about 110 feet long by 40 feet wide, and the W pool crescent-shaped and twice as wide. The bottom area including both pools and isthmus was 250 feet long by 130 feet wide. Talus sliding was nearly continuous at 8 a.m., the pools were splashing, and from the SE at 9:39 a.m. the channel S of the "island" was filled with fallen stones. Thick fumes were rising along the edge of the inner pit, especially where this fall had taken place, as though during this sinking, the thickest fuming tended to migrate inward toward the active center. The island remnant was high and flat-topped, and the W pool active around its borders.

March 30, both pools were crusted, especially the eastern one; Old Faithful was hissing and spouting under a bank. New Faithful in the western pool was more active. Flame holes and boiling pots were seen dimly about the floor. Avalanches were less numerous. The lake as a whole appeared stagnant, low, and approaching stationary condition.

The week has been rainy, and rain vapor in the pit mingled with volcanic fumes makes it difficult to judge the volume of fumes. The glow of the lava on the fume cloud at night has become dull and dark red as seen from the Volcano House. March 31 and April 1, there was very little seeing of detail within the pit in daytime, but continuous or intermittent hissing and some splashing was heard, and occasionally the noise of sliding rocks. In the night a few glowing lava pots could be seen.

As the Director is about to leave the Observatory for a stay in Honolulu, and work of repair and construction is to be done, the weekly reports during April will be written by Mr. Wood.

The following are temperature measurements of the hot fissure N of Halemaumau known as the Postal-Card Crack. They were measured with mercurial thermometer of Jena glass made by Henry J. Green of Brooklyn.

	Temp. air	*Temp. fissure*
March 25, 9 a.m.	23 C.	323 C.
28, 7:30 "	16 C.	318 C.
29, " "	14 C.	317 C.

During the latter part of February and the early part of March, 21 shocks were registered:

February 7, 1:45:38 p.m. to 1:46:30 p.m., H.S.T.
Intensity, very low I, Cancani scale.
February 10, from 6:37:51 p.m. to 6:38:51 p.m., H.S.T.
Intensity, medium I, Cancani scale; origin distant 12.5 miles.
February 13, from 6:18:44 a.m. to 6:20:08 a.m., H.S.T.
Intensity medium I, Cancani scale; origin distant 17 miles.
February 13, from 2:47:22 p.m. to 2:48:12 p.m., H.S.T
Intensity, medium I, Cancani scale; origin distant 28 miles.
February 13, from 2:54:53 p.m. to 2:55:55 p.m., H.S.T.
Intensity, high II, Cancani scale; origin distant 14 miles.
February 13, from 2:59:37 p.m. to 3:00:08 p.m., H.S.T.
Intensity, extremely low I, Cancani scale.
February 16, from 6:42:44 a.m. to 6:43:59 a.m., H.S.T.
Intensity, low I, Cancani scale; origin distant 25 miles.
February 20, from 4:58:55 p.m. to 4:59:31 p.m., H.S.T.
Intensity, high II, Cancani scale, origin distant 15 miles.
February 26, from 10:48:09 p.m. to 10:49.3 p.m., H.S.T.
Intensity, medium I, Cancani scale; origin distant 20 miles.

March 3, from 4:09:17 a.m. to 4:10:10 a.m., H.S.T.
Intensity, very low I, Cancani scale.
March 3, from 5:19:08 a.m. to 5:20:23 a.m., H.S.T.
Intensity, very low I, Cancani scale; origin distant 31 miles.
March 6, from 9:00:53 a.m. to 9:02:10 a.m., H.S.T.
Intensity, low I, Cancani scale; origin distant 18.5 miles.
March 7, from 2:31:03 a.m. to 2:33:30 a.m., H.S.T.
Intensity, low I, Cancani scale.
March 8, from 11:32:43 p.m. to 11:33:47 p.m., H.S.T.
Intensity, very low I, Cancani scale; origin 15.5 miles.
March 9, from 8:55:44 a.m. to 8:57:38 a.m., H.S.T.
Intensity, high II, Cancani scale; origin 25 miles.
March 10, from 00:54:24 a.m. to 00:55:07 a.m., H.S.T.
Intensity, very low I, Cancani scale.
March 10, from 5:02:28 a.m. to 5:03:40 a.m., H.S.T.
Intensity, low I, Cancani scale; origin 14 miles.
March 10, from 7:39:11 p.m. to 7:40:33 p.m., H.S.T.
Intensity, low I, Cancani scale; origin 15 miles.
March 10, from 10:02:41 p.m. to 10:04:12 p.m., H.S.T.
Intensity, low I, Cancani scale.
March 11, from 2:18:09 a.m. to 2:20:02 a.m., H.S.T.
Intensity, high II, Cancani scale; origin distant 22.5 miles.
March 13, teleseism of moderate energy. The motion of the first phase began at about 10:32:54 p.m., H.S.T.; the second phase probably at 10:39:08; the chief phase at 10:42:55 p.m.; maxima of earth motion were registered at 10:43:53 p.m. and 10:44:13 p.m.; motion continued to be recorded until about 11:42 p.m. This shock originated about 2700 miles from this station. Its intensity at this place was extremely slight, far less than the feeblest of local shocks.
March 14, from 6:21:27 a.m. to 6:23:15 a.m., H.S.T.
Intensity, low I, Cancani scale; origin distant 30.5 miles.

The foregoing shocks were registered during Mr. Wood's absence from the station in late February and early March.

During the past week the following shocks have been registered:

March 27, from 6:17:30 a.m. to 6:19:07 a.m., H.S.T.
Intensity, low I, Cancani scale; origin distant 15 miles.
March 30, a moderately registered teleseism. It is judged that the first phase began at 5:18:20 p.m., H.S.T., and the second at 5:26:06 p.m. The chief phase began distinctly at 5:32:44 p.m., and there were distinct maxima at 5:33:51 p.m. The origin was distant, probably between 3600 and 3800 miles.
April 1, from 12:31:05 (noon) to 12:32:08 p.m., H.S.T.
Intensity, low I, Cancani scale.
April 1, from 5:48:01 p.m. to 5:50:11 p.m., H.S.T.
Intensity, low I, Cancani scale; origin distant 18.7 miles.

There has been only ordinary registration of tilting or microseismic motion during this week. There have been strong, sporadic volcanic vibrations.

To permit construction of foundations and installation of a two-component Bosch-Omori 100-kilogram tromometer, the seismographs now in operation must be partially dismounted. Consequently routine seismometric registration will be suspended for a month to 6 weeks. The instrument to be installed is mechanically and dynamically superior to those hitherto in use here, and probably a larger proportion of teleseismic records will be written, as well as more precise records of local shocks. Since August 1, 1912, 152 shocks have been registered here, of which only five or six were from distant sources.

WEEK (9 DAYS) ENDING APRIL 10, 1913

The volcano has reached a condition which makes routine observation almost impossible. Consequently very little time has been spent at the pit and this report is generalized.

By daylight the lower part of Halemaumau is obscured completely by swirling fumes, though these are less in volume than during the low stage last September and October. Hours commonly intervene between favorable eddies permitting glimpses of portions of the lava lake. This is now almost completely frozen over. Survey of the lake is out of the question. Winds from the NE have blown steadily and strongly. Glimpses by night are more frequent than by day.

For the past 5 days the illumination of the swirling fumes at night has diminished steadily, indicating that more and more of the molten surface has crusted over, lessening the area of the residual open pools and boiling pots. Illumination has been more and more concentrating its effect in the center of the smoke column, suggesting that the magma surface has sunk. Fewer avalanches suggest that there has been less collapsing. Hissing accompanies the rush of gases from the constricted vents in the frozen surface of the lake. The evening glow is dim.

Week Ending April 17, 1913

During the last 2 days the volcano gives promise of increased activity. Previous to this it had assumed an unusually dormant condition, with the magma lake almost completely encrusted, so that it displayed even less eruptive energy than in September and October last.

On the night of April 12, at long intervals small portions of the floor were seen dimly through the fume veil. No molten pool was seen, and, judging by the illumination, there was no open pool at any part of the lake surface. Occasional small avalanches were noted. Flaring, due to fountaining of Old Faithful, was barely noticeable. Glimpses of the Old Faithful orifice showed only a short gash in solid crust, probably an opening at the top of a small cone. There was no pool in its vicinity. It is inferred that the magma column was still sinking.

Judging from the illumination, from the reports of frequent visitors, and from the noises of eruption, this condition continued until April 15, except for a brief glimpse of a small pool W of Old Faithful the evening of April 13.

April 15 there were frequent bright flarings in the illumination of the smoke cloud, that sometimes persisted for a minute or two. Except for these no illumination was visible. There was subdued moonlight. This flaring was due to the irregularly periodic action of Old Faithful, and the more prolonged glaring was occasioned by small flows. Old Faithful had resumed its normal condition of an open pool. Thus the vent displayed the phenomena of a rising magma column.

During the morning of April 16 the noise of eruption was louder and more continuous, and one visitor reported an open pool in the afternoon.

Good progress has been made in the reconstruction of the seismographic laboratory and the installation of equipment.

Noisy Jets of Gas:

With the profound lowering of the lava column to a narrower funnel of confinement in the bottom of the pit, the escape of gas became very noisy, described as "harsh blasts", and this characteristic of lowering lava was noticed frequently in subsequent years. The sinking of lava to the repose period of 1913 was thus accompanied by a choking of the gas in the lava by fallen debris, by a constriction of the throat about 600 feet down, and then by a dying away of the evidences of gas pressure, but not by any farther sinking of the live lava column. That column, crusted over, remained present and in evidence throughout the year of repose. The constricted bottom appeared to be the narrow part of the hour glass, and the top of the dome-shaped magma pencil must have widened out below. If that had lowered rapidly and voluminously, as it was destined to do in 1922 and 1924 (Pls. 45b, 51, 53), the unsupported overhang would have collapsed, and the pit would have greatly enlarged. There was no such enlargement at this time.

Knowing now that the 1913 low level and repose of Kilauea was the end of a cycle controlled by some restoration of crustal pressure, the violent gas noises marked a local application of that pressure, and the age-long energy of the greater lava column of the Hawaiian system was expanding itself in intrusion under Mauna Loa, in preparation for the high summit eruption there in November 1914. At that same time the lava came back into Halemaumau (Pl. 12c).

Week Ending April 24, 1913

The molten lava is very low in Halemaumau, but increase in eruptive energy is noticeable. The observed tendency to rise was checked on April 17. Huge avalanches of talus blocks swarmed down into the bottom of the pit, burying the pool and blow holes at the bottom and reducing the illumination so that for several nights following the glow was scarcely visible from the Volcano House; often no glow could be detected. The swirl of fumes increased so that views were rare. At night glimpses could be obtained.

April 20 at night a pool of molten magma reappeared at the Old Faithful orifice, and one or two blow holes were dimly seen. During April 21, the eruptivity increased, and in the morning of April 22 a small flow ran into the open pool from a blow hole. Throughout April 22 and 23, the noise of eruption was tremendous. There were harsh blasts at intervals of about half a minute so loud as to resemble the roll of musketry commingled with the sound of the exhaust of a powerful steam engine. Frequently these noises lasted for 10 to 15 seconds, often loud enough to drown conversation. These blasts were produced by the violent discharge of gas and lava in small blebs, from a small and narrow orifice just above the Old Faithful pool and N of it. In the evening this prolonged *discharge* of small, irregular globules of molten lava, some of which were hurled upward probably 80 to 90 feet, looked like a giant rocket. During the quiet intervals, and just at the instant of outburst, a blue flame flared from this blow hole, reaching upward sometimes several feet. The noises emitted by these outbursts were louder and more prolonged than any heard last autumn when similar phenomena prevailed.

Quiet air on April 22 permitted frequent glimpses of the bottom of the pit affording opportunity to measure the depth to the molten surface of the pool. This was determined as 554 feet below the NW triangulation station. Owing to oblique intersection and high angle of inclination necessitated by prevailing smoke conditions, this depth measure is not precise.

The pool was very small and enclosed by inner cliffs possibly 10 to 20 feet high. During one view it would be boiling violently and would show active fountains; at the next glimpse it would heave sluggishly. Several blow holes were seen in a very small marginal area of black floor crust from the outer boundaries of which the talus slopes rose sharply.

The area of what we usually term the lake—approximately level surface of floor crust and open pool—is not longer than 100 to 120 feet in the E-W direction by 60 to 80 feet N-S. This is smaller than at any time in the last few years.

Week Ending May 1, 1913

The volcano continues to seem more active. There have been merely minor fluctuations of the molten surface, without measurement of depth. Frequent short glimpses of the bottom of the pit, together with an occasional longer view, have been obtained from the NE station.

Notable variations in apparent vigor were indicated by the noise of eruption as well as by changes at the bottom of the pit. The small molten pool gradually became encrusted, and there was a noticeable decrease of noise of eruption. On April 27, nothing could be seen except a few small glow holes, and only hoarse intermittent wheezing was heard. This condition continued until shortly before 10 p.m., April 28. Glow over the pit until then could scarcely be seen from the Observatory, but suddenly the smoke column became brilliantly illuminated and so remained, with much flaring, for many minutes, after which the illumination became more subdued, though plainly visible. Throughout the night of April 28 occasional brilliant flarings were seen, though none was so bright or so prolonged as the first. A visit to the pit showed that a molten pool had reappeared, where the pool of last week had been. Its area was slightly larger, and far more active. It was in continuous ebullition, and there was vigorous fountaining. The first observation was made about three-quarters of an hour after the outbreak, and by then large stalactites were pendent from the low clifflike margins of the pool. At considerable intervals very slight avalanching of talus took place.

The orifice where rocket action was so conspicuous last week had become a sluggish boiling pot largely crusted over and traversed by jagged cracks. It looked as though a small flow had just poured out of it. Possibly the sustained illumination seen for some time following the outbreak was caused in part by this, but more probably it was chiefly due to the breaking up and engulfing of the crust which had formed over the pool, with the usual vigorous ebullition which accompanies such a break-up.

The illumination gradually died down until, late on the evening of April 29, the glow once more was hardly noticeable from the Observatory.

During a trial run of the new Bosch-Omori seismographs (Pl. 4b) from April 29 to 30 a feeble teleseismic disturbance was registered in the E–W component. In both components frequent groups of strong volcanic vibrations were seen. These instruments are not yet adjusted.

Week Ending May 8, 1913

The pool crusted over so that on May 1, only a few glow spots could be seen. On May 2 no noises could be heard and the glow was very feeble. By day on May 4, during an occasional brief glimpse of the bottom of the pit, molten lava was seen, and by night the fumes concealed all. The depression of the congealed lava surface stands a little over 550 feet below the NE rim.

On May 4 there was almost no noise and fumes were swirling quietly. At long intervals a very faint low breathing sound was heard. Since then no change in this behavior has been observed. There is now less activity than at any time since the establishment of this observatory.

For the seismographs trial runs are being made. Several earthquakes of feeble energy and near by origin have been recorded, together with many groups of pronounced volcanic vibrations; without timing apparatus it is impossible to determine yet the time or dimensions of these.

Week Ending May 15, 1913

No molten lava has been seen in Halemaumau. Glimpses of the bottom show that coarse talus blocks now make up the floor and cover any glow holes or cracks that otherwise might appear there.

Owing to the dense cloud of swirling fumes, only now and then can the lower part of the pit be seen and measurement of depth is not attempted. The configuration of the lower part of the pit indicates that the depth is approximately the same as that last determined—a little more than 550 feet below the northern rim. Heavy talus avalanches fell on May 10, at intervals, and slight ones occurred at long intervals on May 11. Such action usually indicated sinking of the magma.

A slight diminution in fumes is suggested by the fact that brief views into the deeper portions of the pit are more frequently obtainable.

During short trial runs of the seismographs, interrupted by adjusting, no earthquake has been registered, and there has been a scarcity of groups of volcanic vibrations.

Week Ending May 22, 1913

Molten lava has not reappeared. Views on May 17–19 showed a small, deep hole, with bottom beyond the angle of vision and talus-block slopes rising away from its margin. This orifice may have existed, hidden in the fumes, ever since the retreat of the molten magma or formed later with progressive subsidence. Views of the bottom in the early part of last week seemed to show only talus blocks on the floor. Avalanches continue to occur at long irregular intervals. The volume of fumes seems to be diminishing but is variable according to weather and wind conditions.

For seismic activity at about 8:30 a.m., May 15, a moderate local shock occurred; motion was registered for 4 minutes. This originated between 65 and 70 miles from the Observatory, intensity medium II, Cancani scale, or about one-third the energy of a felt earthquake.

May 15, a moderate focal shock of much less energy was registered.

On May 16 feeble waves belonging to the chief phase of a teleseism of low energy were registered for several minutes at 1:30 a.m.

On May 18, on the N-S seismogram, feeble waves of the chief phase of a teleseism of small power were registered for about half an hour beginning at 2:45 a.m.

May 18, a few minutes before 8 p.m. a moderately strong focal shock was felt at the Volcano House and generally felt in Hilo, where it occasioned mild apprehension. This shock was beyond the range of high magnification seismometers—the record being instantaneous sweeps of the pens off their recording drums to the E and S. The origin of this shock probably was close to the Observatory. Its direction from here is estimated to be NW. Though not an alarming shock its intensity was high VII of the Cancani scale, or IV–V of the Rossi-Forel scale.

A weak shock in the late forenoon of May 19 was registered sharply, though feebly, by the Bosch-Omori tromometers, more markedly on the E–W seismogram; it originated almost immediately beneath this station.

At about 8:05 p.m. May 20, a weak focal shock, reaching intensity high II, Cancani scale, was registered. This shock originated 24 miles away.

Later in the week groups of strong volcanic vibrations occurred.

Week Ending May 29, 1913

No activity, beyond the copious exhalation of white fumes, has been detected. No molten lava is visible, even in clear views at night. There is no noise of eruption, no avalanches of any considerable magnitude have been heard, and the fumes seem to diminish in volume.

No earthquake has been registered and nothing noteworthy in microseismic motion or surface tilting. Occasional groups of sharp volcanic vibrations have been registered, including a 4-hour period in the early morning of Friday, May 23, when strong motion was practically continuous especially in the N–S component.

WEEK ENDING JUNE 5, 1913

No marked change appears in Halemaumau. Convergent slide rock makes the bottom area, a depression between 500 and 600 feet, with open spaces emitting fumes at several points. Good views of the bottom were obtained the afternoon of June 1, when the fumaroles were grouped around the border of the bottom area, the densest vapor rising from the tumble of debris on the N side. These fumes were white, but more bluish smoke rose from a cavity near the position where Old Faithful was last seen in April, on the E side of the bottom. The bluish fume rose more rapidly than the white.

Since May 4 no noise of eruption had been heard. On May 30 very faint detonations were heard. June 1, these had increased to a rumble with some puffing, with a rhythmic interval like Old Faithful, the periods of quiet lasting 40 to 70 seconds. Inspection of the bottom at night revealed no glow. June 4, the noise increased to strong hissing and harsh blasts, glow was reported and an avalanche was also heard. This succession of events suggests increase of activity, which is usually expectable with approach to the solstice, June 22.

Three very feeble earthquakes of local origin and two disturbances from distant origins have been registered.

A very feeble local shock, intensity low I Cancani, occurred at 4:49 a.m., May 29, motion being registered for about a minute. This shock originated 17 miles away.

May 29, at 11:37 a.m., a very feeble local shock was registered for about a minute, of intensity began at about one-fourth the perceptible minimum, high I Cancani. It originated 12 miles away.

A teleseism was recorded on May 30, from 1:24.5 a.m. to 2:45 a.m. This originated about 4000 miles away. It was a shock of alarming and destructive intensity at the origin. The chief motion about 1:41.5 and lasted for several minutes.

During the registration of this earthquake a feeble local shock superposed its registration upon the waves of the second phase of the teleseism. Its motion was registered for nearly a minute beginning at 1:38 a.m. It originated 12 to 13 miles away and reached an intensity low I Cancani.

At midnight June 3–4 the chief phase of a teleseism was recorded feebly from 11:43.5 p.m. to 12:18.5 a.m. The wave period indicates that the origin was not very remote and at the origin it was a moderately destructive shock.

WEEK ENDING JUNE 12, 1913

Halemaumau is dormant, no glow was visible June 5 or 6, and no glow has been seen since. The strong hissing and blasts have declined; by June 6 they had diminished. Visitors to the pit have noticed low, breathing sounds, and occasional avalanches have been heard. The exhalation of fumes continues.

Seven local earthquakes, have been registered:

June 5, from 3:38:51 p.m. to 3:39:31 p.m., H.S.T.
    Intensity, I–II Cancani; 0.2 to 0.3 the minimum perceptible. Origin 7 to 10 miles.
June 6, from 4:39:09 a.m. to 4:44:50 a.m., H.S.T.
    Intensity, medium I Cancani; 0.1 the minimum perceptible. Origin 50 to 60 miles.
June 6, from 11:40:21 p.m. to 11:42 p.m., H.S.T.
    Intensity, medium II Cancani; 0.3 the minimum perceptible. Origin 25 miles.
June 7, from 4:42:28 p.m. to 4:43:36 p.m., H.S.T.
    Intensity, medium-high I Cancani; about 0.2 the minimum perceptible. Origin 16 to 20 miles.
June 8, from 7:41 a.m. to 7:44 a.m., H.S.T.
    Intensity, IV Cancani; from 1 to 2 times the minimum perceptible. Origin not more than 9 miles, probably less. This shock was plainly felt from Hilo to Naalehu, and in part of the Puna district.
June 8, from 2:11:35 p.m. to 2:12:20 p.m., H.S.T.
    Intensity, I–II Cancani; about 0.25 the minimum perceptible. Origin about 11 miles.
June 8, from 5:43:09 a.m. to 5:45:33 a.m., H.S.T.
    Intensity, III–IV Cancani; from 0.6 to 1.0 the minimum perceptible. Origin 16 to 18 miles.

WEEK ENDING JUNE 19, 1913

There has been a slight increase of activity. On June 11 and 12, the noises of eruption were increasing, low intermittent rumbling with loud hissing and sharp gas blasts—not so loud, however as the noises heard in April. On June 13 these noises continued, and in the evening an incandescent spot was seen near the bottom of the pit. The noises of eruption were somewhat augmented June 14, but by daylight no incandescence could be seen. The noises continue with slight diminution in intensity. On June 15 at night, a glow hole, at the top of a small cone near the bottom of the pit, appeared, and a blue flame wavered above it. On June 17, an incandescent place was noted a little above the bottom of the pit, under the eastern precipice. No incandescent lava has been noted in daylight, and the smoke cloud at night, seen from the Observatory, has not been perceptibly illuminated. The bottom of the pit is choked with fallen blocks. No depth measure has been practicable for several weeks, owing to fumes and absence of glow points of molten lava, but the depth approximates 600 feet.

Eleven earthquakes, ten of local origin, have been registered:

June 13, from 1:58:02 p.m. to 1:59:14 p.m., H.S.T.
Intensity, medium II Cancani; 0.3 the minimum perceptible. Origin 13 miles.
June 13, from 2:14:19 p.m. to 2:14:40 p.m., H.S.T.
Intensity, medium II Cancani; 0.4 the minimum perceptible. Origin a little over 6 miles.
June 13, from 2:15:42 p.m. to 2:12:03 p.m., H.S.T.
Intensity, low I Cancani; less than 0.2 the minimum perceptible. Origin 15 miles.
June 13, from 3:53:27 p.m. to 3:54:02 p.m., H.S.T.
Intensity, I–II Cancani one-fourth the minimum perceptible. Origin a little over 17 miles.
June 13, from 10:34.5 p.m. to 10:52.6 p.m., H.S.T., the chief phase of a teleseismic disturbance of moderate initial energy.
June 14, from 8:26:34 a.m. to 8:26:52 a.m., H.S.T.
Intensity, low I Cancani; less than 0.2 the minimum perceptible. Origin 13 miles.
June 14, from 8:32:43 a.m. to 8:35:04 a.m., H.S.T.
Intensity, low I Cancani; less than 0.1 the minimum perceptible. Origin 70 miles.
June 14, from 1:32:03 p.m. to 1:32:30 p.m., H.S.T.
Intensity, medium-high I Cancani; 0.2 the minimum perceptible. Origin 10 miles.
June 15, from 12:18:19 p.m. (noon) to 12:19:25 p.m., H.S.T.
Intensity, medium-low I Cancani; 0.1 the minimum perceptible. Origin 62 to 69 miles.
June 16, from 5:25:25 a.m. to 5:26:02 a.m., H.S.T.
Intensity, II--III Cancani; half the minimum perceptible. Origin 10.6 miles.
June 17, from 5:46:02 p.m. to 5:46:34 p.m., H.S.T.
Intensity, medium IV Cancani. Very rapid movement in earth but also very small, not felt. Origin very near, less than 5 miles.[7]

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[7] The first printed weekly bulletin of the Hawaiian Volcano Observatory was June 28, 1913, following this narrative.

PART 2—KILAUEA AND MAUNA LOA: 1909–1935

THE CROSS OF HAWAII

To appreciate what experiments with an active volcano really mean, it is essential to study an actual volcano first. Therefore, Kilauea of Hawaii, which ranks among the continuously active of the world's volcanoes, along with Stromboli of the Italian islands, Nyamlagira of central Africa, and Ambrym and Tanna in the New Hebrides, will be exhibited as a type.

Definitions of "activity", "volcano", "eruption", and "lava" we may leave until after we have visited the Kilauea firepit. Kilauea will be presented as it behaved for 26 years from 1909 to 1935. From this behavior will be selected materials for comparison with its action during the preceding century.

From these materials and comparisons will be drawn analogies with other volcanoes. The activities of these other volcanoes, such as Vesuvius (Pl. 10c) in Italy and Sakurajimain in Japan, will be examined. From it all we shall see that Kilauea is not exceptional, but a healthy, vigorous, normal individual of the volcano family.

The period from 1909 to 1935 includes a violent steam-blast outbreak, which the textbooks call "explosive". I do not care for the word "explosive", because a violent volcanic eruption is a rush of vapor, and not an explosion in the chemical sense of a sudden gaseous reaction instantly ended. Nor is the volcanic phenomenon at all like a steam-boiler explosion, which is a gaseous expansion instantly ended. This distinction is the more important because true chemical reaction of mixed gases producing sudden ringing detonations occasionally occur in spatter cones and caverns of the Hawaiian lavas. These are true explosions, are comparatively small, and are rare. The most violent of the steam-jet eruptions such as Bandaisan in Japan may disrupt the side of a mountain, but they take an appreciable time in doing it, and this time is occupied, often by an engulfment and by a vast rush of vapor like the exhaust of a locomotive (Pl. 50a). Moreover, steam-blast eruptions make fragmental ash; Hawaiian gas fountains do not.

Kilauea has been studied intensively and continuously from an observatory on the brink of its crater since 1911, and its rising and falling lavas were studied by Americans throughout the nineteenth century. Moreover, measurements at the observatory have been conducted by the author so that the information is first-hand. Detail and additional illustrations may be found in the routine publications of the Hawaiian Volcano Observatory. Dimensions here are given in round numbers. In Part 4 are details of surveys.

The year 1909 is a good year to begin with, because until 1913 the lava was intensely active but receding. From May 1913 to May 1914 Halemaumau was dormant, with hot vents in its bottom around the edges of the lava column, the top of which was about 600 feet below the rim. Then began a rising that ushered in the culminating cycle of more than a century.

Halemaumau is the heart and hearth of Kilauea fires. It is the speedometer, pressure gauge, lava-level indicator, and mileage recorder of the underground lavas of the island of Hawaii. All through this chapter the words shore, floor, lake, inner overflow, crags, benches mean the inside of Halemaumau.

Hawaii is the largest and southeasternmost of the Hawaiian Islands. It is 100 miles long and 85 broad, with four volcanoes making a cross over most of it (Fig. 14). Mauna Loa is the tree of the cross trending northeast and southwest. Mauna Kea (Pl. 72) is the top of the tree, and the two arms are Hualalai on the northwest and Kilauea on the southeast. All are volcanoes, and off to the northwest is another volcano, Kohala, extending the island into a peninsula headed toward Haleakala on Maui, which is yet another volcano, having a record of live lava flows within the time of human history.

Roughly the heights above sea level are 4000 feet for Kilauea, 13,700 feet for Mauna Loa and Mauna Kea, 8200 feet for Hualalai, 6000 feet for Kohala Mountain, and 10,000 feet for Haleakala.

This part is a narrative and may generalize quantities. Mauna Kea is the grandparent, and Kilauea and Hualalai appear to be offspring along two fissures at right angles to each other that start at Mauna Kea's summit. Mauna Loa seems to be the grandchild, heaped about its present crater, built in the spoon enclosed by the slopes of the other three, midway between Kilauea and Hualalai; Mauna Loa is still extending itself by lava flows in a great rounded promontory out into the Pacific to the southwest.

Geological mapping may demonstrate some sequence other than this, but the physiography, the intense activity of the overflowings of Mauna Loa which threaten some day to bury the crater of Kilauea, the crowding of the northern flows of Mauna Loa into the valleys between the other mountains, and the free sweep of its southwestern flows in a fan of imbricating lavas which are extending the island in that direction all give evidence that Mauna Loa is the great active center of the island's progress in its present-day upbuilding (Pls. 58, 63).

A volcanic island is nothing more than a built-up heap of lava. The nineteenth century produced 2 lava flows from Hualalai, 3 from Kilauea not counting its crater flows, and more than 10 flank outflows from Mauna Loa, besides countless floodings of the great crater basins and pits of Kilauea and Mokuaweoweo (Pl. 64). The crater floors were built up many hundreds of feet. The twentieth century has produced probably 4 outflows from Kilauea (1 below sea level), 5 from Mauna Loa, and further flooding of the craters. This makes 24 outflows between 1800 and 1935, averaging one every 5.66 years.

THE LAVA PIT HALEMAUMAU

The lava pit Halemaumau has been spoken of as the heart of Kilauea (Pls. 9, 10). It is also the pulse of the island, for the fluctuations of the upward-pumping lava in Halemaumau kept pace with the outflows and the sinkings of lava in Mauna Loa. The Mauna Loa vents were 22 to 30 miles away, yet their action was reflected by alternation in the behavior of Halemaumau in 1903, 1907, 1914, 1916, 1919, 1926, 1933, and 1935 (Pl. 86). We shall learn that Kilauea and Mauna Loa are all one volcanic system. Moreover, intrusion of magma in the whole range of underground forms from batholiths of granite to sills of the volcanic rocks is just as much volcanism as is the outpouring of lava at a volcano. This gives to volcanology an added interest, because near Tokyo, New York, Edinburgh, and Rio de Janeiro there are ancient lavas among the rocks that are indexes of the hot slag which still lies beneath. Tokyo has live volcanoes close at hand. It is the task of volcanology not only to interpret with instruments how the ground behaves where visible magma appears at the surface, but away from volcanoes to interpret with the same instruments what that magma is doing when it moves subterraneously where the visible lava does not appear. This is the link that ties volcanology to seismology and may carry the science far afield into all the lands where tilting, trembling, rising, falling, heating, and cooling of the rocks are measurable.

What is this lava pit? It is an inner sinkhole or engulfment depression, nearly circular, with steep walls, occupying an eccentric place in the flattish dome-shaped floor of the greater sink called Kilauea, or Kilauea Crater. By engulfment depression is meant the place where liquid lava keeps an upright vent or well full as a conduit when it is flooding the crater floor. When the lava sinks back, the walls of this well avalanche inward, the lava fill retires to a certain point and congeals (Pl. 79), the tumble of debris rests on top of the lava column, and what remains as a conspicuous feature is a funnel-shaped pit. The words pit and rim herein refer to Halemaumau.

This pit since the early part of the nineteenth century has been the scene of the greater lava lakes during times of effervescence or foaming up of the incandescent lava. Sometimes the pit has overflowed the outer crater floor (Pls. 26, 78), but there have been long periods when the liquid melt has bubbled and splashed inside the pit. At these times it rises and falls, usually from 200 to 600 feet down, without sufficient gas energy to froth it up to overflow. Since 1913 Halemaumau has changed from 1300 feet to 3500 feet in greatest diameter. It was even greater at times during the nineteenth century. There is an 11-year cycle of risings for both Mauna Loa and Kilauea, ended by a repose period for the entire system (Part 5).

PHASE 1909–1913 THAT CLOSED A CYCLE

GLOWING FOAM FOUNTAINS OF KILAUEA, 1909

In 1909 the lava lake in Halemaumau was from 250 to less than 100 feet below the rim, the marked rise being recorded in September. By October 10 the lake was 140 feet below the rim. The surflike roar of the incandescent fountains in linear migration was loud enough to be heard at the Volcano House 2 miles away. The lake tended to circularity with built-up ramparts and an even inner floor sloping away (Pl. 10). On October 27 about one-third of the floor area toward the north side was occupied by the fiery lake. This lake rose and fell through a range of 30 feet within its inner pit. In November Pele's hair, or drawn-out glass (Pl. 5b), floated in the air in great quantities, and a photograph of December 23 shows great number of traveling fountains and bubble fountains, a circular lake bordered by grotto domes, and a general appearance like one of the craters on the moon (Pls. 9, 10).

At Christmas time the east-west diameter of Halemaumau was 1267 feet, the highest spatter rim 90 feet below the north rim, the average height of the bubble fountains 6 feet, and occasionally spray was thrown 35 feet. The rate of surface streaming was estimated as 350 feet per minute. There was at least one bubble fountain for every 12-foot square of the lake, making about 650 fountains in all.

HALEMAUMAU IN ACTION, 1910–1911

Numerous overflows of this effervescing lake of slag upon its encircling inner rim built up the platform at the beginning of January 1910. It was possible to descend to the inner floor. A rhythmic fountain, "Old Faithful", is mentioned at this time. The first of February there were periods of activity 2 or 3 hours long followed by a period of quiet of about the same length. The Old Faithful intervals averaged 30 seconds, and a subsidence period about February 12 broke down the margins and lowered the lake 40 feet within its bench. This subsidence continued through March. Risings were reported in April and June, and a big subsidence in July, when the lake was estimated to be 450 feet down (Brun, 1911, p. 232), and big clouds of smoke were rising. The streaming appeared to come from the western side of the pool, and the biggest smoke hole was southeast of the lake at a craterlet with dislocated rocky walls. The streaming was estimated as 200 feet per minute, and the surface skins were tumultuously sucked into fountaining grottoes at the east side of the pool.

A big peaked island in the lava lake was formed by disturbance of the bench about August 1910, and was still there in November. There was pronounced subsidence in the autumn, but there was activity with the island persisting throughout the winter of 1910–1911. The border bench of January 1910 was preserved, and during the spring of 1911 a new inner floor was created by rising so that by May there was an oval lake with streaming from the west, the island in the larger eastern half of the lake was 30 to 50 feet high, and about a dozen fountains sometimes played at one time around the island. The island in the summer of 1911 changed position, the lava fluctuated in height in July–August, and a whirlpool of downsucking lava formed under an arch between the two halves of the island in mid-July.

FIRST WORK WITH ELECTRIC THERMOMETERS

Scientific records were begun by Perret and Shepherd (Hawn Volc. Obs'y. Report, 1912). Tests of temperature of the lake lava were made with electrical apparatus hung from a cable across the pit (Pl. 9a) which recorded 1000°C. 2 feet below the surface skin of the middle of the pool of molten basalt. At this time the lake was depressed 250 feet below the rim (Perret, 1913b).

THE RISE OF DECEMBER 1911

There was a general sinking of the lava column from July to mid-October 1911 (lowest depression, 450 feet) and a rising to within 35 feet of the inner northeast rim bench of Halemaumau at the end of December 1911 (Diagrams, Pl. 74).

With the rising, smoke diminished, fountaining increased, the lake overflowed, and by December 22, 1911, the lake was 80 feet below the rim of the pit. On December 27, the spray of the fountains could be seen from the Volcano House (Pl. 84). There was no island, and the lake of fire extended virtually from wall to wall; this was like the situation near the end of the next cycle, January 1924 (Pl. 48c). The maximum height reached by the lake was about 65 feet below the true rim. The fiery bursts of

Old Faithful (Pl. 11, large fountains) played at unusual intervals of 2 or 3 minutes. Blue flames could be seen all over the lake through cracks in the crust.

THE SUBSIDENCE OF JANUARY 1912

On January 3, 1912, the lava was within 2 feet of an inner northeastern shelf dating from 1894, but on January 14 it had dropped 80 feet.

At this time the Hawaiian Volcano Observatory (Pl. 1) was built. On January 17 the lake was 742 feet long east and west and 218 feet below Halemaumau rim. Next day it was 30 feet lower and 180 feet shorter. The Old Faithful interval had quickened to from 30 to 40 seconds. There was a high narrow bench of January 4 partly caved, and there was a tumble of fragments and islands of hardened bench magma below. A spatter cone with whitish flames was built in one cove. The subsidence continued, and flames were seen at smoke holes on the high wall of the inner pit.

At the end of January (Pl. 84a, map of Kilauea) the lava was 339 feet down, then it turned and built a new inner overflow floor and fluctuated around 260 feet for several months. A pinnacle was left in the talus southeast representing the broken bench matter of the previous high level. At this time we did not extend measurements to this bench and talus region, later known as the bench magma or epimagma, and so the early mapping was confined to the lake itself (Part 1). The bench matter moves up and down.

Streaming changed direction, and there were diurnal fluctuations of rising and sinking of the liquid in its cup. Some rising and sinking phases were noted at about 10-minute intervals with 20 fountains during rising and only 5 during sinking.

SPRING RISING OF LAVA, 1912

General rising occurred in March and April 1912, after a low level about the equinox, and the lake within its overflow bench diminished from 600 by 300 feet March 12, with depression 282 feet, to 434 by 244 feet and depression 220 feet April 25. This would imply an overhang beneath the liquid or a building in of the ramparts, unless the substance of the overflow cup and lake bottom is built inward as much as the shores. With continued rising of the lake 20 feet more to May 23 the lake enlarged to 465 by 263 feet. The lake was now overflowing its shore line continuously, there was a big flow cone at the pinnacle which had filled the southern part of the bottom, and new lava springs broke through the walls or talus of the pit 19 feet above the lake and sent five cascades down to the outer edge of the platform.

Day and Shepherd (1913) collected lava gas by pumping it from a spatter cone on the bench at this time.

MAY-JUNE SUBSIDENCE, 1912

From May 24 to June 22, the lake subsided 129 feet within a pit in its caved bench. The bench on June 22 stood 70 feet above the lake. Allowing for the caving back this means that the bench since May 23 had slumped 50 feet, but it did not go down *en masse*—a situation very different from the mass subsidences of bench magma in 1918–1919 (Pls. 78, 79). Apparently the conduit was small. There were six smoke holes at various levels above the lake, jumbles of sulphur-coated boulders, and crevasses. *The lake enlarged to 530 by 290 feet, implying collapsed overhang of border*

FIERY EFFERVESCENCE, JULY 1912

There now began a month of remarkable fountaining effervescence, with rising of 6 to 42 feet per day, dwindling of vapor, and enlargement of the lake cup. Thus enlargement could be achieved by cup construction.

FESTOON FLOWING

The sunken bench was buried under a new platform, and the following is a description of the mechanism of pahoehoe overflow on the bench June 29, 1912:

The lava attacked the bank with fountains and seemed to mount it in a series of surgings. It poured over a bank having no rampart and spread into a puddle. The surface skinned over, and the newly arriving stream made a channel through this skin. The skin wrinkled in folds parallel to the front. Strands drawn out at the sides of the stream made longitudinal side curtains. The transverse festoons (Pl. 73f) are twisted into ropes when the middle moves faster than the sides and the top lava moves faster than the bottom. Red glowing fissures were maintained open between the stream and its side curtains (Pl. 19).

When the festoons at the lower extremity of the flow stagnated, toes of glowing melt emerged from under the skirt. These protruded a few feet in cylindrical masses. They appear to come from tubes under the festoons and they harden. The festoons ceased to move and were revived by overflow twice. The inner portion of the flow was liquid and incandescent, but this showed only on the margins and at the source.

The new ribbon of source liquid at the narrow part of the fan almost instantly changed downstream from lemon yellow through orange, cherry red, purple, purple gray, and silvery gray to brownish black with a gray sheen. All the overflows on the platform showed heavy drapery folds from overflooding in broad sheets.

No one who has not seen the process can imagine what a delicate surface of vesicular glass webbing new lava has (Pl. 6). It is perfect only while hot; the minute it cools it begins to snap and decrepitate, crack and oxidize, so that the collected specimen is never like the new skin.

On July 12, 1912, the lava of Halemaumau reached its high level of 192 feet depression, then subsided on successive days 21, 28, and 20 feet. The lake measured 550 by 325 feet, smaller than at the low level of March but larger than at the low level of June.

The fluid was boiling over its entire surface with tremendous fountains and nearly without blankets. This process had been continuous for 10 days. The rumble was heard 3 miles away. Much blue vapor rose from the bombarded ramparts. Traveling fountains developed where the warring surface currents met. The spray built up great spatter ramparts (Pl. 17a). When the rapid sinking began, a straight line of fountains formed, like two downpouring cataracts meeting.

From July 9 to 13, people on the pit edge had to wear masks, as the heat was intolerable, and the night glow on the clouds was seen all the way to Maui.

Skin formed wherever the lava foam was rising from a well below. The supply wells are maintained as vertical gas channels, through partly congealed lava. At an overflow locality a skin protruded over the edge or shore, and from the extension of the skin on the lake side the streaming on the lake surface would be directly toward the lake and away from the overflow (Pls. 15a, 21a). This meant that skin was over lava foam rising in a low dome, with streaming over the lake as a current and over the bank as a flow. The under-lake was increasingly viscous where gas loss created vesiculate stiffening (Shepherd, 1938).

Old Faithful was the largest fountain in the lake over the main sinkhole at the lake bottom, frequently exploding in three or four, almost simultaneous, great bursts or bubbles. The intervals were measured as 50, 15, 45, 80, 15, and 30 seconds, with 15 as a marked secondary interval. The sinkholes are vertical channels of downflow in the foam circulation. The other fountains frequently migrated with the current like floating bodies.

This means perhaps that such a fountain represents a large gas bubble confined beneath a stratum of incandescent slag more viscous than the layers below, and resulting from coalescence of vesicles rusing from a sinkhole well. Old Faithful is probably a center of convergence of such migration over the downpouring.

GREAT REACTION OF DOWNFLOW, AUGUST 1912

Subsidence set in through August, punctuated by short spells of rising; islands formed of broken bench magma, and fume increased. At the end of August the pit was an obscure smoky jumble with pools hissing about 500 feet down; this was 300 feet lower than in July. September was a month of smoke, noise of slides, and of puffing, the two former indicating subsidence, and the puffs indicating rising. By the end of September the pools were 580 feet down. (*See* Part 1.)

A blowhole had taken the place of Old Faithful. This is natural, if Old Faithful is over the main sinkhole. The pot had become constricted with spatter accretion, and through the orifice every 30 or 40 seconds a spurt of lava spray was ejected 100 feet or less, with a rocketlike noise. A sheet of liquid lava at the end of the spraying was vomited sideways, and these splashes were building a cone (Pl. 30b). The convectional circulation was still flowing but was crusted over.

ACID FUME

The sulphurous acid fume, 1912–1916, was so strong on the west side of Halemaumau that a steel cable fragment was completely decomposed between January and August 1912.

AUTUMN UPBUILDING OF BOTTOM HALEMAUMAU, 1912

October 1912 continued to be smoky, a crusted lake formed, the depression lessened from 580 to 375 feet, and this was brought about by upbuilding of the bottom with overflows. Often these were from the Old Faithful pot in the crust.

In November (Figs. 3–6), fountaining and streaming ponds opened. On November 13, the Old Faithful area collapsed so as to double the size of one pool and to restore the rhythmic fountain to its normal habit. A cataract poured through a horizontal tube from the western to the eastern pool. The roof of this tube collapsed and revealed a torrent pouring from one pool to the other. With the rising, all the pools united, but in mid-November there was some subsidence from 370 feet of depression to 390 feet.

ADVENTURE IN GAS COLLECTION

On December 4, with the lake about 360 feet down, Shepherd of the Geophysical Laboratory collected gas from the flame of the cone vent on the floor. With lava 218 feet down, a similar descent had been made May 28, 1912.

The vacuum tube was attached to a bamboo pole, its tip was inserted in the flame crack of the cone, and it was sealed permanently with a gasoline torch. Five samples of gas were collected. (*See* Part 1, also Jaggar, 1940, p. 316.)

PHILOSOPHY OF FROTHING BASALT

A western conelet (Pl. 73a) broke open on December 12 and poured a torrent over the floor into the lake. The vent was 6 feet higher than the lake. The advancing flow weighted down the platform crust, which rifted again and again along the front of the flow, so that glowing lava from beneath welled up the cracks and merged with the lava of the flow.

This showed that the upper layer of the platform was a slightly crusted flow. A region of excessive and continuous overflowing on the bench may eventually develop into an arm of the lake, particularly if deep cracks in the bench magma exist there. The size of the liquid pool and the width of the platform probably vary with the amount of gas heating supplied.

What is the source of all the rising and falling lava when no new matter is added, and no lava inflow escapes outside the crater?

The column merely rose and fell in Halemaumau through a vertical range of 600 feet between 1894 and 1918. If there were no submarine outflows, approximately six million cubic yards of foamy lava has welled up into view at times of rising only to solidify, shrink, and collapse within the pit at times of sinking. Perhaps all the flux and ebb is remelting by hot gas and contraction or intrusion when gas flow ceases.

IS THERE A LAVA TIDE?

Hourly observation of the crater was attempted for some time at the beginning of 1913. The depression of the lake was 380 feet. An hourly run of measurement for 22 hours January 7–8 indicated:

Lowering 4 feet	6 to 10 a.m.	Rising 4.5 feet	5 p.m. to 6 p.m.
Rising 5.5 feet	10 to 11 a.m.	Lowering 3 feet	6 p.m. to 2 a.m.
Lowering 2.5 feet	11 a.m. to 5 p.m.	Rising 5 feet	2 a.m. to 7 a.m.

This was the first suggestion of a lava tide (Brown, 1925) which was subjected to more rigorous examination in the summer of 1919 (Pl. 32).

The lava at the bottom of the pit (1913) was pouring from west to east around a fingering peninsula in a broad river, and quietly pouring under the platform, blankets and all, at the south cove.

EFFECT OF COLD RAIN

In a heavy cold rain at 8 p.m., January 18, 1913, the east arm of the lake became dark and stagnant, excepting at Old Faithful. The streaming stopped. The west pool started streaming in the opposite direction. At the same time tremendous tumultuous fountaining began at the west end, splashing high on the banks, and a similar effect in less degree was seen all around, a notable white glow appearing in the fountains which developed under the bank in the south cove. The pool hissed and rumbled. Then it became quiet and dark, with very few small fountains, and covered itself with thick blankets. Old Faithful broke through as usual, and slowly the eastward flow was resumed. The pit filled with steam, and the lake became invisible. (*See* description of Plate 73e.)

TIDE-LIKE FLUCTUATIONS

On February 1, 1913, the lava rose to depression of 363 feet, and there were fluctuations of as much as 6 feet in 4 hours. (For detail *see* Part 1.) The tidelike fluctuations were (Jaggar, Finch, and Emerson, 1924; Brown, 1925):

Rise 6 feet Tuesday to Wednesday.
Drop 6 feet Wednesday evening.
Rise to flooding 10 feet Thursday.
Drop Thursday evening 5 feet.
Rise to overflow bench Friday morning.
Drop Saturday 3 feet.
Rise Saturday night 1 foot.
Drop Sunday over 2 feet.
Rise Sunday night 1 foot.
Drop Monday morning 2 feet.
Rise Monday forenoon over 1 foot.
Drop Monday evening over 2 feet.
Rise 3 feet Tuesday morning February 11, 1913.

FINAL VERNAL SUBSIDENCE OF 1913

The peninsula was converted into an island by breaking away from the bench February 16–17. The lake became a ring around a small glistening black island. The end of February 1913 the lava fell 90 feet, making cataracts from the west pool, which was 15 or 20 feet higher than the east pool.

The first week in March 1913 showed extraordinary fluctuations in level of the lava pool, in one case a rise of 41 feet in 1 hour and 10 minutes. The week's range was between 500 and 412 feet depression. The conduit was becoming constricted. The torrent from west to east made a remarkable spiral whirl on the streaming of the east pool (Pl. 11). Spectacular activity developed, with a cascade pouring over a submerged sill into a hole at the edge of the lake, also rapid rising that temporarily submerged the island and the bench overflows.

ENGULFMENT AND DIGESTION OF TALUS

After mid-March sinking set in, a high bench at the north wall of the pit fell in, and there was a New Faithful as well as the big domes of Old Faithful. Apparently two sinkholes were needed. Talus was sinking, and during 6 months the lava had been consuming a great quantity of waste from sunken benches. This consumption goes on in many peripheral cracks, filled with lave below the talus and fuming above. The gases open these into small craterlets, revealing the deep glow and engulfing many tons of slide rock. Recent work by K. T. Mau in Kilauea Laboratory, University of Hawaii, has shown, in experiments of 1939–1940 that SO_2 decomposes basalt even at low temperature in a few months. This peripheral activity may alternate with the more spectacular activity of the rising lake, the alternation being controlled by the conflict between the heat supply and increased engulfment of talus. Benches continued to cave in at the end of March 1913. The engulfment and digestion of talus must play a part in the rise and fall. The only ingredient above melting point is gas.

The pit became more obscured by fumes in April, the liquid pools became crusted, and the confined gases hissed and puffed. March 29 the depression was 522 feet. There were two pools, each with its rhythmic fountain. There were many avalanches.

POSTAL-CARD CRACK TEMPERATURES

Temperature measurements of the Postal-Card Crack (*see* Part 1) seemed to indicate that its variability was hardly more than what the air-temperature variation determined; thus: March 25, air 23°C, crack 323°; March 28, air 16°, crack 318°; March 29, air 14°, crack 317°.

Illumination at night dwindled during April. Old Faithful flared, and the noise of the fountain grew louder in mid-April. Big avalanches fell on April 17, partially obliterating the pool. Rocketing from a blow hole developed with noise like musketry. The depth to lava lake on April 22 was 554 feet. The lake was only 100 by 60 feet. At the end of April the pool opened and closed, with much blowing, and in May the pit became quiet and smoky. It remained dormant in June 1913.

CYCLE THAT FINISHED IN 1913

At the beginning of 1913 there was in Halemaumau pit a swirling and fountaining lava lake within more or less crusted lava that represented the top of the lava column, which had been receding from a high level in the winter of 1909–1910. There had been, in fact, a series of pulsations of rising from a low pit about 1902 to spectacular fountaining activities from 1906 on, and there had been a vigorous outflow of clinkery lava from the southwest rift of Mauna Loa in 1907. This last was preceded 4 years before by gushing lavas in Mokuaweoweo Crater at the top of the big mountain. After 1910 the pulsations of the top of the Halemaumau lava column increased in range, and there was very violent ebullition of fountains in Halemaumau in January and July 1912 (Pls. 74, 86).

PHASE OF BOTH CRATERS THAT BEGAN THE CYCLE 1913–1924

DORMANCY YEAR, 1913–1914

By May 1913 the lava column in the pit had withdrawn to smoky depths of over 500 feet, and except for blowing noises and slidings of broken rocks all was obscured in great quantities of vapor and fume rising from big smoke holes in the talus around the sides of the bottom of the pit.

In July 1913 temporary glow for a night or two indicated the presence of the lava column and of flaming gases in the bottom of the pit. At such times there is always a decrease of steam and fume. In August the pit was deathly quiet with neither glow nor noise, and only a silent, dense column of vapor filling the pit, rolling off to leeward, and permitting no view of the bottom.

STRONG EARTHQUAKE, OCTOBER 25, 1913

In the autumn fitful activity was resumed with some feeble gushing of lava seen before a strong earthquake occurred on October 25, felt throughout the Hawaiian Islands.

This earthquake was exceptional in that it shook down avalanches from the walls of Kilauea Iki and of the greater crater of Kilauea in several places, making fresh, brown scars and new talus slopes. It came in the dead of night and was sufficiently violent to be alarming at the Volcano House and to throw some stones into the road which leads to Halemaumau.

Immediately after the earthquake the pit notably increased its gushing of lava in trickling streams into its bottom from holes around the edges of the bottom, and with the increased combustion of inflammable gas and the drying effects of increased heat the vapor and fume thinned.

FORMATION OF NEW LAVA LAKE, 1914; A NEW 11-YEAR CYCLE BEGINS

The winter of 1913–1914 carried this recovery forward very gradually, and the lava distinctly rose in May 1914 after just a year of quiet. Floor pots and cones occasionally gushed over flat lava surfaces in the bottom of the pit during the summer of 1914, and in the autumn these merged, by the caving in of the pots and of tunnels which connected them, into a lake with several arms (Pl. 12c, d). Rate of rising increased, and the bottom of the pit, which had been 554 feet down, when measured April 22, 1913, and near 600 feet in summer, 1913, had reached in August 1914 a level 585 feet below the rim, and the amount of rising from May 5 to August 12, 1914, was 84 feet.

MAUNA LOA CRATER ERUPTION, 1914

This rising in Halemaumau heralded an outbreak of Mauna Loa (Jaggar, 1915; Wood, 1916) at the summit crater, Mokuaweoweo (Pl. 3), on November 25, 1914, and the fountains in Mokuaweoweo continued some flooding of the floor of that crater until January 11, 1915. As soon as these summit fountains stopped and the lava column in Mauna Loa sank, the lava lake of Kilauea began to withdraw, and the bottom of Halemaumau pit became a tumbled and cracked mass of debris. That ended the first phase of rising for the cycle 1913–1924 (Pl. 12, 74).

PHASE 1915–1916 TO THE SECOND MAUNA LOA OUTBREAK

INTRODUCTORY STATEMENT

The year 1915 showed recovery at the beginning of the summer after low and smoky conditions in Halemaumau during the spring, with the top of the lava column about 440 feet below the rim (Pl. 75). There was a pronounced rise from June to September until the pit was only 360 feet deep; during this period observers could see the development of islands in the lava lake which tended to tilt up at one end and turn into crags. By photographing and measuring these crags, there now began a most interesting investigation to determine of what differentiated parts the top of the lava column really consists.

BENCH MAGMA AND LAKE MAGMA

The quiet, smoky depths of the 1913 pit had been occupied chiefly by tumbled talus in a funnel remnant from the collapses of the end of the last cycle. The lava which had built up some 250 feet of bottom between September 1913 and September 1915 had appeared to be chiefly a rising puddle of liquid lava with a flat floor of its own overflows around its edges. Now there appeared flat-topped islands like shoals in a mud flat when the tide recedes, and all the time the liquid lava pool was receding and rising by a small amount within its own border ramparts. When the fume cleared, so that measurements could be made frequently, by means of a transit and base lines on the edge of the pit, these measurements indicated that not only the liquid lake rose and fell, but also the platform around it. In other words, the well under the lake was drilled through some sort of a cemented paste that had formed around the talus funnel of 1913, and that cemented paste was rising as well as the liquid inside the well. The two did not rise and fall together from hour to hour, but they did from month to month. Thus the lake could recede enough to leave its ramparts 5 to 15 feet above the splashing fountains, or it could rise enough to overflow its ramparts and to drown the islands. Quite apart from such added height to the seemingly solid platform by overflow, this "land" around the lava lake proved to be red hot inside and to lift or lower independently of the lake. Moreover, it could lift locally so as to tilt up independently of the lake level. The presence of islands gave every indication that the lake was shallow but not that the islands were floating (Pl. 11d).

One of these islands developed a form triangular in plan, and the peak of the triangle rose until the islet stood up above the lake as a tetrahedron. On one occasion it moved horizontally in the course of a day, seeming to pivot about a vertical axis around one of its corners, but it was not floating (Pl. 14a, b). The bench around the lake, including this red-hot island material (red hot inside as seen down cracks, for the surfaces were black lava), came to be called the bench magma, to distinguish it from the much hotter, highly liquid and frothy lake magma.

COMPOSITE NATURE OF BENCH MAGMA

By September 1915, the 250 feet of new lava which had risen in the bottom of the funnel consisted of (1) the old slide-rock slopes of 1913, (2) the new liquid lava, (3) the partially congealed saucer of overflow products of the lake, and (4) the partially congealed bottom material of the lake sometimes making shoals and islands. The measurements proved conclusively that these islands were part of the lake bottom and were not floating. The measurements of temperature and experiments have proved that the liquid lava cannot melt the old slide-rock slopes of 1913. The liquid lava must have percolated through the crevices between the rock fragments. It cooled and partially solidified. Therefore, a cross section of the top of the lava column of this time was a stiff paste rising with the old talus breccia cemented in it, with a ring platform carried on its crest, the whole somewhat cylindrical in shape, and a shallow cup of unknown depth inside the ring platform, the cup containing the lava lake, and the latter fed by a well or wells maintained for an indefinite distance downward through the midst of the column of stiffer lava. Up these feeding wells came the hot gas froth, with its gases burning at the surface, that imported from somewhere below the new fundamental magma heated by gas reactions and thereby liquefied and vesiculated to a fluid very different from the fundamental magma deep down, where under pressure it is presumably stiff, rigid, and heavy (Sections, Pls. 77–81).

ENLARGEMENT OF THROAT BY SUBSIDENCE AND RECOVERY

September 1915 produced a crisis of subsidence accompanied by many small earthquakes whereby the lava lake receded, the marginal bench cracked funnel-wise and caved in, and the entire lava column lowered with a surging liquid puddle in the bottom of the new funnel of subsidence, but with all the integrity of the complex constructional lava saucer destroyed.

This lowering was from 360 feet to 480 feet below the rim of the pit. The subsidence was like the one of the preceding January, but greater. The greater lowering may have been due to a greater clearing out of the throat below. This throat had been full of talus during the quiet time of 1913. The rising in the liquid lava and percolation of acid gas and liquid among the crevices of that talus had appropriated the talus fragments as part of the bench magma column. This column had risen from a narrower throat below to a wider funnel above. Consequently liquid lava occupied the ring channel between the risen column and the outer wall. Therefore with every pronounced rising followed by a rapid subsidence it seems likely that the throat is cleared bigger, and the pulsations of subsidence are permitted to go deeper. Examination of the curve showing sudden drops in January 1915, September 1915, and June 1916 indicates that each drop was bigger than the one preceding (Pl. 75a).

The autumn of 1915 showed two developments of great significance with reference to the structure of the stiff lava column and the liquid lava occupying wells within it: sinkhole cascades at the east and source wells of rising at the west.

CASCADES OF LAVA

Powerful fiery cascades developed, pouring from the lake into coves and into a small outlying east pond which seemed to be connected by a tunnel with the main lake. These cascades mark a lack of hydrostatic adjustment in the frothing liquid. The lake is fed by a rising conduit elsewhere, but some of the wells are drained below during the subsidence and breakage of the stiff lava column and so become sinkholes. The circulation of the froth is indicated by the streaming action on the surface of the lava lake. At all times probably some of the wells act as sinkholes, but the slag pool is too deep to show anything more than a streaming toward such points. When the lake lowers within its saucer the rapid downrush at the sinkhole forms a cascade (Pl. 13).

OLD FAITHFUL FOUNTAIN

Probably a sinkhole under the middle region of the main lake at this time and for years before created what is called Old Faithful. When a sinkhole functions as a cascade, vast quantities of gas are released by the cascade stirring. When the lake is deep over the sinkhole probably the gas vesicles are stirred together in the narrow well and periodically create a large bubble which rises through the heavy slag to the surface and makes a fountain. The periodicity of Old Faithful was often 40 to 70 seconds, and this interval was probably a function of the rate of streaming, the size of the sinkhole, the vesicularity of the lava, and the depth of the lake (Pl. 12).

WESTERN SOURCE WELL

The conduit up which the lava rises through the stiff paste was apt through these years to be at the west side of the bottom of the pit. This was called the west pond (Pl. 14d). The form of the whole lake was like a lobate lava flow pouring from a narrows at the east side of this pond. The west pond would stay crusted over, with the streaming pouring out from under the crust eastward over the surface of a long pool, with each stream line ending at a glowing and splashing grotto. In these border grottoes gas is released which has been imprisoned under the skins on the lake.

GAS HEATING

The energy of gas heating is capable, for a given volume of inflowing lava, of keeping a certain percentage of the lava a foamy liquid. This is the lava lake. The remainder becomes semisolid, the lake bottom; or solid, in the case of lake overflows. These two materials, the lake bottom and the still red-hot under portions of the overflows or benches, are apparently continuous a few feet down at a temperature of about 900°C. The liquid lava with its rapid circulation maintains a temperature of about 1100° C, contains much gas, and the incessant loss of the gas at the fountains determines expansion cooling, a loss of the heating agent, and a loss of mobility. (*See* "Glass-blowing", Part 4.) So a convectional system of wells develops.

EASTERN SINKHOLE GROTTOES

The border or end grottoes fling up slag on the bank and build half-domes or ramparts with glowing stalactite caverns inside (Pl. 30d, e). Occasionally they are over sinkholes. Just as a central sinkhole may produce a rhythmic fountain, so a border sinkhole will produce a grotto fountain. However, with an excess of gas confined under the solidifying skins on the slag, and the streaming steering those skins to certain places on the bank, the rending of the skin determines gas escape and fountaining on the bank. In the same way with excess of gas, central or migratory fountains often form and produce what are called continuous fountains where a rupture of the skin releases accumulated gas below. The absence of fountaining over the source pond appears to mean that the vesicles there are small and uniformly crowded, there has been no irregular stirring to concentrate them, and the gas-lava mixture comes from a place of confinement where the combustible gases have had little oxygen. Oxygen of the air carried down in submerged crusts in contact with hydrogen, carbon monoxide, and sulphur vapor, which are present in the vesicles, brings about new reactions in the lake, as is shown by the abundant flames at the fountains (Photograph in Bulletin, August 1918).

FORMATION OF TILTED CRAGS

Back at the western source pond and the lobate lake extended over the floor of the pit east of it, the lava column began to rise in October 1915, so that by November 30 feet had been recovered. The rising was largely by overflow of the floors around the lake. However, crags of the tumbled floor material of the summer time were left, and these as part of the fabric of the bench magma tended to lift and tilt away from the lake while floods of heavy, new lava flow weighted the margins of the floor back of them. Consequently these crags form escarpments commonly with a dip slope away from the center of rising and a steep face toward the center. This steep face shows a series of terraces marking successive slag shore lines lifted above the lake as the crag tips over backwards. Frequently the weight of overflows in the wall valley seems to cause centrifugal tilting of the crags, as though the flows and the crags were isostatically balanced.

LAVA LAKE A CONFINED LAVA FLOW

We have spoken of this lake of the autumn of 1915 as resembling a flow. The whole mechanism of lake formation in the bottom of a funnel of talus in a pit begins with driblet flows from vents in the talus. These driblet flows crust over, and we get a vent, a tunnel, and a lava front. If the front is confined in a pit, we get a vent, several tunnels, and a lava crust. If the tunnels cave in we get a vent and a pool, the latter at first following the curves of what had been tunnels. Thus a lava lake in a pit is nothing more than what would be a flow if it were on a mountainside. The great flows of Mauna Loa have a liquid stream and overflow fields at the sides of the stream. These overflow fields are the bench magma, and the stream is the liquid magma. In the pit, however, there develops by confinement a condition of heat conservation and long-preserved internal glow of the bench magma which differs from the overflow fields of the mountain flank. This should give the student some vision of how the conduits, tunnels, and sinkholes in the bench magma are formed, with the convectional pumping up and down of the whole lava column through such a sequence as is represented by our curve of the cycle (Pl. 74).

The resemblance of the lake to a lobate flow may thus have been more real than accidental. In fact the spring of 1916 developed tremendous overflows of the lake inside Halemaumau, and one of these at the west poured between two broken halves of a crag which gradually split in two and doubtless also opened a chasm in the bench magma below (Pl. 14). This western overflow became a pool with definite rounded plan of its banks, within which the liquid rose and fell, and finally the lake changed its shape and developed a big extension at the west. The autumn of 1915 led up to this with general overflowing in November and December, and a somewhat stagnant situation at the end of December with some avalanches.

ONLY GAS CAN PRODUCE MELTING

The temperature of the rising melt is insufficient to fuse rock fragments immersed in it. Gases and their reactions produce melting, and these gases are in limited quantity sufficient to keep the lake lava liquid. Most of the liquid lava is undercooled and incapable of melting its shores or the walls of its wells. When a mixture of gas and slag comes up from the depths rapidly, it probably enlarges the wells and lakes at the expense of the bench magma.

LAVA ISLAND MOVEMENTS, 1916

From January to May 1916, the lava of Halemaumau was rising. The overflow of the floor and the breakage of the bench magma column below developed in April a big S-shaped lake (Pl. 14a). Two crags became islands, and around them, with the rising, the lake became elliptical. Always the west end was the source, whence the streaming flowed eastward. The crags tilted in different directions.

Finally the island crags moved horizontally; one of them migrated bodily north with rotation around its west point as a vertical axis; this closed a cove and brought the north horn of the island close to the shore of the lake.

The lake overflowed its platform margin voluminously in May, and rising was very rapid. The suggestion was that the two island blocks of bench magma were undermined and sliding toward the Old Faithful funnel hole. This spurt of very rapid rising preceded an outbreak of Mauna Loa.

LAVA FLOW OF MAUNA LOA, 1916

On the southwest rift of Mauna Loa at 7:51 a.m., May 19, there was a high gush of vapor and foamy lava about the 10,000-foot level (Pl. 58). There were numerous earthquakes May 20 and 21. At 11:15 p.m., May 21, a flow burst through the rift (Pl. 58f) lower down above Puu o Keokeo at about the 7000-foot level. This pushed through the forest in Honomalino, South Kona, and progressed 6 miles in 12 hours. It stopped 3 miles above the road. There were several tongues of the flow in upper Kahuku, the lowermost stopping 7 miles above the road.

About the lava fronts there were many gas explosions in caverns believed to be due to mixtures of carbon gas and air, where the flow was in the forest. These explosions were never noticed in the upper country where vegetation was absent; caverns, however, are just as common in the upper country. The advance of the lava streamways or torrents reached a maximum of 5 miles per hour, but for a flow arm as a whole an advance of half a mile per hour was fast. The upper lava near the vents on the Kona side was a rough spongelike pahoehoe; on the Kahuku side it was mostly aa. The lower flows were all aa. No glow was seen after May 27 in looking up the mountain, the earthquakes became fewer and stronger, and a very sharp shock on May 30 ended the Mauna Loa eruption of 1916 (Jaggar, 1917a; Wood, 1917a).

KILAUEA SUBSIDENCE AT END OF MAUNA LOA ERUPTION

Kilauea immediately responded with subsidence (Jaggar, 1917a, p. 257). The lava of Halemaumau had spurted upward for 10 days just before the Mauna Loa outbreak, and during the Mauna Loa flowing the Kilauea lava level declined a little. Fumes increased, and on June 4 the lava lake was about 305 feet below the pit rim.

June 5, 1916, was a very dramatic day at Halemaumau pit. In the morning the lake fell 40 feet in 2 hours. The caving banks of the platform around it were red-hot inside. The small island revealed a stem under the island platform and then toppled over on its side, resembling a stranded boat. Shoals appeared. The lake diminished and became converted into three rushing torrents. Large blocks of the bench caved in, sending up clouds of brown dust and producing violent ebullition in the lake. There was great increase of perceptible heat from exposure of red-hot rock and increased action.

Everything was now tumbling into a funnel, but the lake and its large island crag kept their integrity in the middle. When the wall of the pit proper began to avalanche inward, bright red dust arose in contrast to the chocolate-brown dust of the caving bench magma. A cascade into a hole developed. The Old Faithful fountain continued its rhythmic outbursts. Great collapses of the bench made huge waves across the lake which mounted the talus and coated it with black glass. There were perceptible earthquakes. By 1:20 p.m. the lake was fully 500 feet down and consisted of two sluggish puddles, a cascade pouring from the talus, and the imperturbable Old Faithful. Cheesy flow of aa lava oozed out from the breaks in the bench magma. At one place 20 feet above the lake a spring of lava flowed down like a brook, coming out like an artesian well. In the afternoon there were tremendous avalanches (Pl. 13a) from the pit walls, and vertical whirls on the edge of the pit carried clouds of grit so as to make it difficult for an observer to stand up.

In the late afternoon a heavy cloud overhung the interior of the pit, the glowing rivulet was still flowing, the talus was red-hot, enormous avalanches were tumbling, there was marvelous coloring in the walls, and the rising clouds of dust and smoke were all shades of red, salmon, black, brown, and coffee color mixed with white steam in boiling cauliflowers. A spouting cone on the bottom was bellowing and thudding explosively.

The next day there were continuous clatter of falling stones, and occasional big avalanches, and the lake, about 400 feet long, was a small pond in the bottom of a funnel of talus. Just after noon a general inrush of the talus occurred, and the lake boiled hotly in a thousand small fountains, while clouds of brown smoke shot into the air. The depression was 690 feet below the rim of the pit.

PHASE 1917–1919 TO THIRD MAUNA LOA OUTBREAK

RECOVERY OF HALEMAUMAU, 1916

Avalanches continued, but a fortnight later, in June 1916, the lake had resumed rising and exhibited satiny skin, four or five active grottoes, several central fountains, and Old Faithful steadily at work under the northeast bank. By June 23, the lake had risen 100 feet. A platform developed around the edge, and one portion of this platform started to smoke, crack, and rise in terraces (Pl. 15a). This rising of the lava column was rapid, as shown in the curve of the cycle (Pl. 75), and there were incessant overflows of the border platform so that the big talus heaps of June were soon submerged.

On August 1 the lake was a neat elliptical pool within a platform of its own overflow material 447 feet below the rim of the pit. At one side this platform had lifted so as to exhibit eight terraces which were broken through by a big chasm forming a cove of the lake, or a radial channel (Pl. 14c). Two such channels developed northeast and northwest, and streaming developed away from the west channel, the head of which produced an elongated western pond parallel to the wall. This became a source pond at the west, as had happened repeatedly. The suggestion was that the saucer of bench magma had lifted toward the east to make the terraces and sunk toward the west to draw away from the wall, let the liquid lava come up on that side, and develop there the source pond over the wall crack. The lake was now changing its shape, by August 8 there were 22 fountaining areas, crags had developed on both sides of the west channel, overflows and grottoes developed at the south, and rising was in progress about 3 feet per day. Spells of intense overflowing drowned most of the features, there was rapid rising of the crags, a northern island developed, and the rise of the bench magma dominated the rising of the lake magma.

Halemaumau was now approaching the 1917 period when it became accessible for soundings, gas collections, temperature experiments, and all those measurements which made the next 3 years the most productive time in the history of the Observatory for the study of liquid lava.

EVOLUTION OF RISING CRAGS

The end of August 1916 was a time of rapid evolution of crags and islands and a rising of the lakes and ponds, now divided into several units, until the liquid was only a little over 300 feet below the rim. There was now a northwest pond, a new rhythmic fountain in the north part of the lake, Old Faithful had become a cone on the bank, and there was a long west arm to replace the west pond. The small islets were becoming a large crag mass in the northwestern part of the bottom. Strong rising and overflowing continued in September, and banners of flame emerged from the border grottoes. Many photographic studies were made at this time to reproduce flames and fountains by means of different color filters (Jaggar, 1917, volcanologic investigations). By the end of October the lake was 225 feet below the rim.

By November 1, the lava floor of Halemaumau had adopted the form which it held with slight variations through the winter of 1916–1917. This was a large lake with two straight parallel arms extending west on its southwest side, a big crag mass northwest of it, two islands at the east, a long cove at the north, and crags rising from platforms east and southwest. There were four ponds back of the big northwest crag mass, two of them cups in the lifted slope and two in the wall crack. This big crag mass stood 74 feet above the lake, and at this time the bench magma was lifting the crags more than 2 feet a day and somewhat faster than the lake (Pl. 15b).

QUAQUAVERSAL UPLIFT OF SECTOR CRAGS

In November there were big overflows of the platforms. Flames were abundant. Fume from the lava was thin, but frequently a rain cumulus would hang above, occasioned by the indraft of moist air (Pl. 20b). November 17, there was a suggestion of three sectors in the arrangement of the bench magma. These were separated by the western, northern, and southeastern coves or chasms between the several crags. There appeared to be quaquaversal uplift of the sectors in the center (Pl. 77).

TEMPERATURES, POSTAL CARD-CRACK

At this time temperatures were taken of the outlying cracks back from the edge of the pit to the north of Halemaumau which for years had been called the postal-card cracks. This was so called because travelers browned postal cards there. The temperature November 18 of the hottest crack was 313° C, and others varied down to 240° C.

In the pit after the middle of November spouting cones developed by the west wall chasm making a continuous fountain like an artesian well, from which a lava flow poured along the wall valley. Where two of the surface streaming currents of the lake met in the southwest cove a continuous fountain developed. There were small depressions of the lake relative to its banks observed on certain days, but it was necessary to prove that this was depression by angular measurement, as sometimes the appearance of depression was really a relatively greater rising of the bench. Rising was the rule with strong overflows into the wall valley; and on the surface of these flows as they cooled could be heard a steady tinkling sound, due to the bursting of blisters which made glassy needles fall on the lava crust.

DESCENT WITHOUT LADDERS

On December 20, 1916, the first descent into the pit by way of a northeastern talus was made by Mr. Walter Spalding, when the lakes were 117 feet below the rim. December 22, the crust of the western wall pond broke up suddenly (Pl. 20c) when the fragments foundered with much bubble fountaining.

MINIATURE PIT DEVELOPMENT

December 28, the northwest pond became covered with a cone showing a small overflow pot on top. This cone illustrated the manner by which such a pit as the Devil's Throat (Chain of Craters No. 4) is formed. At 12:45 p.m. the lava inside the cone subsided, and suddenly the entire structure collapsed exhibiting a pit 15 feet deep with a splashing pond inside.

1917—CHEMICAL EXPLOSIONS

January 1917 opened with a cascade pouring into the end of the southwest arm of the lake down a sinkhole, and at the north side of the floor a double driblet cone had united its two parts to make an arch, above which there was a single stack 20 feet high (Pl. 17). This was making gobbling noises and bell-like explosions from gas action over fountains inside, and this was one of the very few occasions when the noise resembled the exhaust of a gas engine, and may have been due to actual chemical explosions of mixtures of gas and air.

DETAILS OF FLOOR AND LAKE LAVA AT CLOSE QUARTERS

A visit to the floor of the pit January 3, 1917, is worth describing in detail as showing the impressions of an observer first privileged to walk over the hot lava and stand on the ramparts a few feet from the surging lava lake.

We descended to the floor by the east gulch. The rock of the east bench was lava with rather collapsible brown crusts, but that of the fresh northeast flow was much more solid. We followed the edge of this flow across the floor to the driblet cone and found incandescent, stiff, and spongy lava toes pushing out. A stick was pressed into the moving toes, and the surface was found to be covered with a glassy net membrane, stiff as leather and flexible. The orange hot melt inside was slowly flowable like very stiff porridge and was full of vesicles. A fragment of it could be pulled out much like candy and broken away from the rest with a stick and manipulated for a few seconds until it became as hard as glass. Occasionally the piled lava would rend open on a crack, and the slow melt within, fed by the crusted cone vent, would well forward sluggishly. No flame vent was visible on the cone.

The rampart at the lake edge was smoking strongly, with yellowish-white fume, SO_2 acting on solid lava over a splashing grotto, but this fume was not very oppressive. The lake from 11:30 a.m. to 1 p.m. sank to 10 feet below the inner rim. We walked out on the rampart northeast and looked at the lake surface 10 feet below. Crusts 3 inches thick upended and foundered (Pl. 20c). Tearing skins with zigzag patterns along the line of sundering appeared like a rug several inches thick made of a half-inch fiber, so that ropy filaments formed and stretched continuously at the torn zone; this was all part of the surface texture as the blanket was rent asunder and the stiff gas-charged fluid rose from below, stiffened, and was drawn away so as to pull out its gas bubbles.

We saw fountains vigorously throwing up umbrellas (Pl. 18) of slag 50 feet away, and these were singularly silent. The material is much stiffer than it appears to be from above, coagulating and appearing vitreous in the air as it is shredded, changing color to cherry red and purple, and falling as rods only slightly flexible, and droplets wholly hard.

What fountain gas eddied near us was not oppressive and not at all like the acrid intolerable blue fume from burnt sulphur concentrates at the leeward edge of the pit. Hot air waves were the principal gases noticed. The heat from the lava was quite tolerable, though severe at times when fountains or tearing skins came near. Bluish-white fume from a crack back of the rampart was not disagreeable.

The rampart was covered with black, glossy, glistening glass, the larger splashes nearest the lake, openwork splashes and sticks of drawn glass next, about 10 feet from the edge, while 20 feet back from the edge were smaller Pele's Tears often perfectly formed in droplet and dumb-bell and pear shapes.

The lake surface showed bellying skins with gas beneath, upfolded crusts like a heavy drugget or elephant hide, and upturned crusts, but as a whole the lake appeared level. The pounding in grottoes made no shake and little noise back of the rampart. There are more noises, heat, and fume at the rim of the pit above than on the floor back of the rampart.

We walked through the east valley to the southeast floor (Pl. 16) and found the crusts there more treacherous and hot (Pl. 23b). There were great banks of decomposed Pele's Hair, like rotten hayseed, on the wall. Walking up the southeast rampart, we found the lake pounding hard beneath it and under all the rampart farther south. There was no great inconvenience from fume, but it was worse than at the northeast locality (Pl. 17a). The southeast floor region was generally smoky.

All through January, a time of accessible lava, many experiments and measurements were carried out. The depression of the lake was 67 feet on January 19. Overflows of the floor were still in progress January 27, and on February 1 the crag summits stood above the edge of Halemaumau. Another standing fountain developed at a southwest cone. The liquid lava was sounded (Pl. 21) with pipes (Jaggar, 1917, volcanologic investigations), proving depth of 50 feet.

DEVELOPMENT OF AA TEXTURE

In February there was subsidence, and lava resembling coke appeared under the benches when the lake went down faster than the bench magma (Pls. 22c, 23a). This lava is a form of aa. Indeed all pahoehoe lava underneath its skin is probably potentially aa. If the skin tears after the inner lava has started crystallization and the sugary inner magma is forced out, this material will solidify as aa. Pahoehoe is glass permitted to rise to the top.

REVELATION OF SHALLOW LAKE

With the February subsidence the crags again sank below the edge of the pit, and on February 14 a cascading sinkhole was developed in the middle of the south arm of the lake when the surface of the latter was 102 feet below the rim. This well was 60 feet across with a continuous torrent pouring into it, and the entire bottom of what had been a lake was revealed with a shallow stream pouring across it, indicating that the former lake had been only about 40 or 50 feet deep and confirming the soundings.

SUDDEN LIFT OF NEW ISLAND EAST

The lake fluctuated in level, and on February 18 a new island 40 feet high (Pl. 23a) with a base of aa was lifted rapidly in one night near the middle of the pit, while the eastern crags subsided 30 feet as though a block of the under bench magma had tilted around a horizontal axis, lifting on one side and sinking on the other. This was followed during a new subsidence by a cascade under the bank of the lake in the northeastern arm, which again revealed, in another region, the shallowness of the former lake, as the cascade was down a marginal sinkhole and poured over an edge of lake bottom.

REHEATING OF FLOOR, AND SPATTER CRESCENTS

Fluctuations and relatively low conditions continued in March with risings during the first week and sinkings the second week. A singular phenomenon on a western floor on March 15 was the reheating to glowing of a cracked surface, stained with white salts, by some unknown gas mechanism. There was no flame and almost no fume. With the March lowering the pit was much more smoky. About March 21 spatter crescents were produced in several places by rapid rising; these crescents differ from grottoes in that they have no overhang. On March 27 a lowering of the lake 15 feet showed overhanging walls on all sides, and a small islet appeared like a mushroom (Pl. 24a).

CHANGES OF LAKE AND CRAGS

There was some lowering in April 1917, but rising appeared April 16, and the lake was now an oval of entirely new shape, and the crags all changed as compared with the January profile. April 19, the lake was 71 feet below the rim with the southeastern pool separate from the main lake.

NORTHWESTERN TABLE CRAG, AND LIFTING CRISIS

With the beginning of May 1917, the lake depression was 83 feet, and, from about May 10 on, a block of the northwestern floor rose as a tabular crag. On May 28 there were overflows of the floor, and in the evening came a singular crisis: The lake subsided 10 to 15 feet, the bench magma lifted suddenly in the center of the pit, an immense glowing tunnel appeared with the lake inside revealed by the relative subsidence of the lake lava, and the connection between the eastern arm and the central lake became a canyon. Apparently a central peninsula rose 15 to 20 feet, and there was a sudden tumble of the benches about 7:15 p.m. making a bright glare seen from the Observatory. The inner crag cliffs around the main lake were 40 to 90 feet high. The lava lake immediately recovered, and the next morning there was no canyon;

on this day the lakes overflowed the benches voluminously. All this crisis appeared to be a sudden lift of the sectors and a gushing upward of the liquid lava inside.

LOWERING OF JUNE 1917: FUME VARIATION

On June 2, 1917, there was a sinking; on June 8 an island lowered, and the lake rose; on June 22 the lake depression was 115 feet. There was a distinct lowering when the smoke increased and the benches cracked. Always this smoke effect came on with a lowering owing to acid gas accumulation in voids that were created and more or less condensation of steam. Always with rising the visible fume diminished. June 29, the lake was rising, and the tilt of the bench magma sectors was strong, apparently affected by being weighted with overflows.

TILT OF CRAGS BY OVERWEIGHTING

This weighting effect seemed to indicate that the individual crusted blocks of bench magma are floating on their own stiff bench magma substance; as the overflows from the lakes on their surfaces are generally in the wall valley, and an overflow period is a time of expansion and rising in both lakes and bench magma, this sidewise weighting of a crag restrains the uplift on the side of the pit wall and enhances it seesaw fashion on the higher part of the crag block. Whereas blocks of bench magma *do not founder* in the subjacent paste; crusts of lake magma do founder in liquid lava.

TADPOLE BLISTERS

July 1917 was a time of intense rising in the bench magma and adjustments in the lake. There were disturbed, tilted, and crumbled crags. On July 22 a remarkable phenomenon under thin skin of the hot lake near a grotto was the sudden swelling of gas blisters, made by bubbles. These migrated away from the grotto in quick zigzags without rending the skin, and then disappeared. The effect was like a quick-swimming fish disturbing the surface of water with his snout, darting first right, then left, without breaking through. These were called tadpole blisters. Their vanishing after travel of several feet horizontally was due to escape of the gas through the skin.

August 1917 (Pl. 24b) showed marked rising of the central crag and big tilted platform crags around the sides. Throughout the summer there was a balance with reference to level, with the lava lake about 100 feet below the rim and atmospheric conditions remarkably clear for photography. This lasted throughout September.

SUDDEN CRAG MOVEMENT AND SHORE TERRACE TILTINGS

In October 1917 there was slow rising after equinox, and on October 18 a new cone was emitting a flow at the site of the former west pond. Between October 23 and 24 the flat south point bench over the lake tilted up suddenly so as to convert the point into a peak 40 feet high, leaving a raw wall of structureless aa lifted above the lake revealing the character of the lava that forms the confining walls beneath the liquid. The central crag subsided slightly in compensation of this uptilt.

This southeast crag presented a new surface against which the lake could build a terrace or shore line ,and the ups and downs of lake and bench magma during the next

2 months made several terraces around the base of this crag, which by their relative inclination showed change in directions of tilt of this bench magma block (Pl. 24c).

MEASUREMENT WITH TELESCOPE MICROMETER

On November 19 the inner bench around the lake collapsed in many places by readjustment of the bench magma, and a new inner bench was building by accretion on November 23. Rising was still going on, and the central crag peak had now appeared above the edge of the pit as seen from the Observatory 2 miles away. This made it possible with a telescope containing a scale inside to determine the general rise and fall of the bench magma from the Observatory. Gradually all the crags came into view.

SOLSTICE AND EQUINOX EFFECTS

On December 21 the benches about the base of the southeast crag so converged in dip of surfaces as to indicate that the crag was rotating or tilting around a horizontal axis (Pl. 25a). Solstice or equinox often introduced a short-lived movement, and December 24 indicated subsidence. After Christmas day, however, rising was resumed.

1918, THE YEAR THAT INAUGURATED HALEMAUMAU OVERFLOWS

The lava lake was 61 feet below the rim of Halemaumau pit on January 5; the instruments at the Observatory showed easterly tilt, characteristic of rising, and the crags in Halemaumau were rising rapidly. The bench magma floor of the pit was arching up. The big northeast crag, a huge tilted escarpment of floor, was lifting (Pl. 25b). On January 18 the central crag had become a steeple peeling off on one side, like the Pelée spine, as though the mass were rising and curling over. January 21, a flow filled the northeast wall valley, which before had been a huge depression between the wall and the dip slope (Pl. 28a type) of the northeast crag. There were big flows around the crags at the end of January. A temporary subsidence of the lakes January 24 sent the liquid 30 feet down inside the lake cup and produced whirlpools. By January 31 the liquid was up again (Pl. 26a, c).

END OF MAPPING FROM A PIT RIM LOOKING DOWN

There was rising all through February 1918 (Pl. 25c), and this brought about the first overflow of Halemaumau for this cycle. The inner floor of bench magma at the edge of the lake inside Halemaumau on February 20 was 20 feet below the rim of the pit at the southeast where the road approaches the pit (Pl. 26b); a sudden rise of the lava column that night and numerous overflows brought the bench only 4 feet below the rim February 21. That day there were voluminous floods inside the pit so that at 11 p.m. the inner flow surfaces stood only 15 inches below the southeast rim of Halemaumau. All the crags were now high above the rim of the pit, and the mapping could no longer be done by birdseye sketches taken from a high point looking down on crags and lakes alike.

FIRST OVERFLOW OF HALEMAUMAU SINCE 1894: MARGINAL TUMESCENCE

At 5:10 a.m. February 23, 1918 (Pl. 27a), the southeast rim of Halemaumau overflowed across the road terminus, which was destroyed. At the same time the southwestern trig station at the rim of the pit was lifted into a half dome, and there was general tumescence of the south rim of the pit owing to the grip of the rising bench magma, by wall valley fills crushing the corner in profile which was exposed, when the hard inner lava flows reached the level of the rim and the central sector continued to tilt up.

The flow moved half a mile to the east, with a width of 50 to 300 yards, and flowing started afresh about noon and 6 p.m. There were seven large spatter domes inside the pit, and this period of rising following February 15 marked the most rapid filling with lava at Halemaumau since December 1911. On February 24, fresh overflow destroyed the south trig station and the large A-frame there which had been used in 1911 and later for cable experiments. There was new overflow southeast about midnight February 24–25. The southwest station had now been lifted 10 feet. By the night of February 25 its lift was 12 feet, and the whole south and southwest rim was elsewhere swollen from 3 to 5 feet (Pl. 28c). There were intense overflows southeast and south at 11:30 p.m.

COLLECTING VOLCANIC GAS WITH VACUUM TUBES

March 1, gas was collected in vacuum tubes at flames about the lakes and cones. This work was continued for weeks.

On March 3 the lakes were lower, and the flows were developing swollen domes as the lava inside became more pasty and the freezing of the flows around the edges made it easier for the lava in tunnels to lift the crust rather than escape in toes from under the skirts of the flows.

SUBSIDENCE ENDING THE OVERFLOW PHASE

On March 21 the crags were rising (Pl. 25d), but on March 28 a big subsidence began (Pl. 27b) whereby the entire cylinder of the fill of the pit was drawn down bodily carrying the topography of crags, floors, and lakes with it.

By April 2, 1918, the lowered lake was divided into separate ponds both by drainage through sinkholes, accompanied by inrush, and by burial under talus from broken crags. Where steeper faces of bench magma were left around the edges, aa lava trickled out and cascaded in powdery form down the walls like dross from a blacksmith's anvil. On April 3 the ponds were 250 feet below the rim of the pit, and several days before this the crag summits, hidden by the pit rim, had disappeared from the view of the Observatory (Pl. 27c).

RECOVERY WITH BLOWING CONES

By April 5 there were signs of recovery of the liquid lava, with blowing cones forming, including a notable central one. This suggested the history of the recovery of the whole crater by blowing cones and numerous puddles of lava given by the early missionaries after the subsidence of 1823. April 6, the lakes were rising faster than the crags. April 12, there was a lowering with much smokiness. April 18, the crags were subsiding, and the lake was rising. On April 19 the inner half of the south cone on the edge of Halemaumau, which had been the source of flows outside the pit, caved into the pit, its interior showing grapevine stalactites. A very hot cavern led away from the rim of the pit under some of the February flows.

AN EXPLODING CONE

By April 26 the depression was 174 feet; an extraordinary exploding cone developed at the north, flinging up driblets of lava, developing a form almost like a stove pipe, and making a noise indicative of true chemical explosions by mixture of gas and air. April 30, measurement showed the crag down and the lake up.

ALTERNATIONS OF RISING CRAGS AND RISING LAKE

On May 1, 1918, a large circular floor of inner lake overflow within a ring of talus around the pit walls had been redefined, and the main lake was small and elongated. The lakes and crags alternated in their spurts upward; the first week of May showed an octagonal flat surface for the floor, above which the crag remnants stood in relief. Three of the March crags had been buried under talus and lava floods. The new flows had buried the east ledge and made a new ponded filling of the northeast valley. This process had now happened four times within 15 months. At times the bench magma rose while the lake magma subsided. Thus we get a record as follows:

May 5–6, crag up 2 feet, lake up 7 feet.
Man 6–7, crag up 1 foot, lake down 7 feet.
May 7–8, crag up 4 feet, lake down 1 foot.
May 8–10, crag up 1 foot, lake up 10 feet.

In the third week of May the bench magma swelled up, and there was deep crevassing of the inner overflow floors. Floods of liquid lava poured along the wall valleys. A source of flows again developed at a cone over the old west pond. The bench magma, May 17–24, rose faster than the lake. The last week in May, the liquid lava gained on the crags, but new crags began to form, and a marked movement the last 3 days of the month lifted the marginal talus, this being accompanied by a storm of volcanic tremors on the seismographs and by a tilt of the crags away from the center of the pit.

FLOOR OF HALEMAUMAU RISING FASTER THAN THE LIQUID

A computation at this time showed that the swelling up of the pit floor since the April rise had proceeded nearly 25 per cent faster than the rise of the liquid lava and that it was now lifting the slide rock slopes bodily as the circular plug of semisolid lava pushed upward. A feature of measurements which threw light on the old records of travelers, was that an observer without instruments, referring levels to the floor inside the pit, would have noted a sinking lake, for the walls of the inner basin were growing higher. In reality both lake and margin were lifting, but the latter 25 per cent faster. The average rise for the composite lava column for 6 weeks had been 2.8 feet per day.

CULMINATION OF JUNE 1918, AND FLUCTUATIONS

Rising culminated on June 4 when the lake was 87 feet below the rim, and the top of the central crag 6 feet below. By mid-June the lake subsided 20 feet. At the end of June the lake was 131 feet below the rim. This had reached 144 feet on July 12. Changes were not conspicuous, and after this a stationary condition was observed. The lakes occupied deep inner cups, and the bench magma was somewhat cracked.

This continued into August 1918. The first week of August, however, rising amounted to as much as 13 feet per day, with the bench magma swelling up, the crags tilting back (Pl. 28a), and the liquid welling up the wall cracks so as to imitate the rise of the previous February. The rate of rising diminished to 4 feet per day in mid-August, and by August 23 only the liquid lava continued to rise by filling the wall valleys (Pl. 28b). These fills on the north and southwest came within a few feet of overflowing the pit rim. A driblet heap that formed at the southwest margin of the pit, close to the edge for a length of 100 feet, stood 6 or 8 feet above the level of the edge. The lakes and ponds were now about 30 feet below the rim, with due allowance for differences among them. A flaming cone on the northwest rim permitted photographs and spectroscopic work with volcanic flames for the first time. At the end of August the column subsided slightly to a stationary condition.

Stagnation continued the first week of September 1918, subsidence was about 1 foot per day the second week, and the general situation presented large crags well above the rim of the pit, floors easily accessible, and the northwestern cone broken open revealing stalactites. The lakes at the end of September were 69 feet below the rim. Moderate rising started in October, there were again stationary conditions in the middle of the month, and at the end of October both lakes and crags were slowly rising, the lakes twice as much as the crags. This rise increased strongly and somewhat suddenly beginning October 29.

EARTHQUAKE AND OUTFLOW NOVEMBER 1918, FOLLOWED BY SINKING

This movement culminated in the early morning of November 2, 1918 (Pl. 30b), when, following a powerful earthquake shock, molten lava welled up cracks 170 feet back of the rim of Halemaumau on the north side forming craterlets above the two vents and sending a lava flood cascading from outside the pit over the rim into the pit. Other lava flowed over the Kilauea floor to the north. Now began uplift of the mountain (Pl. 87; Part 3).

With the rise of the lava for 4 days, the Observatory ground tilted sharply to the north and east. At the moment of the earthquake and lava flood the ground recovered from this tilt instantaneously. The central crag was now 70 feet above the pit rim, and the main lake 23 feet below it.

This all inaugurated strong rising with the lava crags tilting back and the liquid lava building slag heaps on three sides of the pit so as to fill the wall valleys. The rim flow of November 2 almost completely buried the old rest house on the north side of the pit, and the northwest rim of the pit was swollen up about 6 feet.

Another gigantic subsidence duplicated the events of the end of March in mid-November preceded by voluminous outpourings of more lava flows from new vents back of the north rim November 10–11. These sent two elongated serpents of pahoehoe far across the western floor of Kilauea Crater toward Uwekahuna.

Subsidence in the pit began about this same time, and the great cylinder of stiff lava surmounted by rocky hills, yawning chasms, and lava pools sank bodily 200 feet, while the liquid lava in its midst rose relative to it and overflowed the banks of the ponds. The only topographic features of the interior of Halemaumau pit disturbed by the subsidence were the marginal portions of the inner surface, broken and piled with debris from the disrupted cliffs. There was left the familiar firepit over 200 feet deep (November 16, 239 feet), with bubbling lava pools amid inner craggy ridges, and the central crag still standing over 90 feet above the liquid. The conviction that the main lava column was a stiff fluid surmounted by the great crags and floors as a rifted crust was inescapable after inspection of one of these subsidences. The liquid at this time filled the rifts in the bench magma for very limited depths and welled up when the bench magma blocks were squeezed in the narrowing funnel of the true crater.

Many local earthquakes and tremblings accompanied the sinking of the lava, the earthquake frequency varying directly with the speed of the downward movement. The seismic activity ceased when the sinking stopped. The tremendous bubbling up of the liquid lava during this subsidence of the bench magma resulted in almost complete disappearance of fumes, making this occasion exceptional among sinking spells. The recovery began November 17–20 when the lake rose 13 feet while the central crags subsided 10 feet. This lowering of the crags and uprising of the liquid lava continued until November 25, 1918, when the entire lava column started to rise, the floors lifting faster than the lakes. The lagging of rise of the stiff crag and lava floor behind the liquid lava for about 10 days repeated the happenings of the previous spring. The liquid rose in flooding spurts with diminishing volume, while the stiffer floor matter tended to rise between these spurts with very marked increase in speed as the liquid spurting spells dwindled. As centrifugal tilt and Kilauea mass elevation was in progress, this entire subsidence of pit content was being compensated by intrusion.

ACCORDANCE OF TILT WITH BENCH MAGMA MOVEMENT

The tilt machine at the Observatory showed accordance between west-east tilt, and the measured fall (west tilt) and rise (east tilt) of the bench magma. The tilt was quite independent of the spurting of the liquid lava. This accords with the supposition that the bench magma is representative of or coterminous with the deep lava column under the center of Hawaii.

LIQUID LAVA SUBMERGES CRAGS AND OVERFLOWS, DECEMBER-JANUARY 1918–1919

Rising continued 3 feet per day, and the bench magma uplift was stronger under the lake bottom southeast of the center of the pit. The crags were borne on the slope of the upheaved pyramid of the floor lava. There were five sources of floor filling tending to make ponds in the wall valley and new floors in a great horseshoe toward the northwest and south. The second week of December produced another slight subsidence of crags with still more intense effervescence of the liquid relative to the bench magma, so that three more crag remnants were entirely submerged under a new flat floor, and only two crags remained besides the great central mass. The flood plain around the lake maintained a 3 per cent radial grade away from the lake basin as a center. The third week of December put the crag down 8 feet and the lake up 13 feet. The week of the solstice was marked by a turning point to rising, from subsidence of the bench magma, as represented by the central crag, which reached its lowest depression of 57 feet on December 19. The lake, then 86 feet below the rim, rose 14 feet in 5 days, and the crag rose 10 feet and then fluctuated. The floor of the pit, about 65 feet below the rim, was a broad expanse of live flows with two areas near the margins of the pit, respectively northeast and southwest, which had built up flat-topped slag heaps (Pl. 29). For 3 days after December 24, these slag heaps built themselves up respectively 17 and 9 feet; the higher northeastern one had a cone vent on top only 25 feet below the rim of the pit. Subsidence began at the end of December, with the flow vents still continuing a heaping of flow lava. The beginning of subsidence apparently generated liquid lava by gas effervescence.

The first half of January 1919 (Pl. 30a) indicated that the semisolid lava continued subsiding but the liquid flooding increased in volume, the latter by layers of lava flow and building up of the slag heaps, compensating for the sinking of what was left of the central crag. The last half of January the southwestern slag heap overflowed the lip of Halemaumau.

Most of lava crags had disappeared so that the floor of Halemaumau appeared to be a gleaming slag heap with fountains on its crest which changed position from day to day. The floodings came from three principal western vents. The floor in places was only 15 feet down and easily accessible. The lake lava was rising more than 5 feet and the last remnant of the central crag rose less than 4 feet per day. When this crag disappeared there was nothing for a surveyor to use to measure the movements of the underlying bench magma.

COMPARISON OF MAUNA LOA-KILAUEA SEQUENCES 1907-1912 AND 1914-1919

There seemed good evidence that when Mauna Loa had finished a cycle of eruptions Kilauea would follow with great lava floodings, and this doctrine of alternation had been stated by Green. In 1903–1907 there was the Mauna Loa flow; 1908–1912 yielded intense Kilauea activity. Now 1914–1916 had produced Mauna Loa flow, and 1917–1919 was yielding intense Halemaumau overflow. Halemaumau in 1911 had craggy islands, in 1912 many hundreds of boiling fountains. In 1917–1918 it had an upper surface of rocky crags, in 1919 it was developing great floods of liquid.

ILLUSTRATION OF VON BUCH'S "ELEVATION CRATERS"

At the end of January 1919 the overflow floors of the pit resumed tumescence of the incandescent bench lava, so that the western lava heap surmounted the old rim of the pit for a quarter of the circumference and sent sluggish lava flows outside the pit to the west, as well as eastward and northward into the pit proper. There were still northeast and southwest slag-heap centers of overflow. The building up of these by veneering or adding new layers amounted to about as much vertically as the swelling of the bench magma under each heap, so that these slag heaps in miniature illustrated Von Buch's (Geikie, 1903, p. 320) theory of elevation craters perfectly. The principal lake for 9 days, January 16–25, rose 1.3 feet per day, and the crag remnant 1.8 feet per day; the average of these two represents the lava column, apart from the slag heaps. On the other hand the northeast slag heap rose 2.1 feet per day, and the southwest heap 3.8 feet per day. Each gush of overflow would be preceded by measurable tumefaction.

PARALLELS BETWEEN JANUARY-FEBRUARY OF 1918 AND 1919

February 1, 1919, inaugurated subsidence effects with withdrawal of the liquid lava more than 20 feet and slumping of lake margins indicating overhang, and the southwest slag heap, which had been producing the biggest overflows, sank more than the rest of the pit floor. That is, the region of the liquid lava source exhibited the subsidence reaction most strongly. The excessive hissing gas pressure which had characterized the overflow period ceased, and visible sulphur smoke increased by condensation and acid attack in the subterranean voids left by the retiring liquid. The subsidence was of the order of from 2 to 4 feet per day.

This sinking was very short lived, however, and early in February (Pl. 30d, e) the lakes were again brimming and overflowing; the south heap overflowed the rim of the pit February 7 and poured 400 feet across the Kilauea floor damaging a new trail at the road terminus. These events of January–February closely resembled those of the same months in 1918.

CAUSES OF PRESSURE RELEASE AND EFFERVESCENCE

The measurements suggested that, as in November 17–18, 1918, the liquid lava was rising and the bench magma sinking. There was a culmination of subsidence when gas was released and induced effervescence. We now had a culmination of rising, with a stagnation crisis in the internal pressures, and a consequent release of gas inducing effervescence. The January overflow had abstracted many hundreds of tons weight from the top of the lava column by overflow of the pit rim, and deep effervescence occurred as in the overflow of a geyser pool.

In the geyser, release of pressure lowers boiling points, and explosive ebullition follows. In the lava column release of pressure lowers saturation points of gas dissolved in glass, and effervescence follows. In both cases a foam forms at the expense of the fluid beneath. The excessive liquid lava of January 1919 was such a foam, and its rising was not a measure of what the stiffer glass below, from which it was derived, might be doing. At this time the tilt seismograph agreed with the crags rather than with the liquid lava, indicating that the rise and fall of the liquid lava was not necessarily an index of the rise and fall of the deep lava column (Jaggar, 1920).

The northeast slag heap built up just inside the rim of Halemaumau in February 1919 until it was 27 feet above the rim and its flows surrounded the eastern stone shelter (Pl. 31), where tourists had stood, and so threatened the wooden tool house of the Observatory that it had to be removed and rebuilt 200 yards farther north. This was the fourth time that this little wooden building had been moved since 1911.

ELEVEN HALEMAUMAU OVERFLOWS 1918-1919

Within the year prior to February 1919, Halemaumau had exhibited overflowing of its rim 11 times at 9 different places. Six of these extended more than 100 feet from the pit, and the southeast flows of February–March 1918 were most extensive, reaching half a mile or more in length; those of November 1918 to the north ranked next, and the flows of January–February 1919 were now tending to fill the gaps between the two earlier localities with overflows to the east, south, and southwest. August 1918 had produced driblet overflows north and southwest.

OBLITERATION OF THE PIT

The appearance of Halemaumau the last half of February 1919 was quite unlike the familiar old-time pit. From the high rim of Kilauea Crater the pit appeared obliterated, and in its place was a flat smoking area, with three lava heaps of slight relief and three inconspicuous circular cups containing the liquid lakes. A semicircle of low rim remained at the northwest only. This smoking surface lay at the summit of the broad, flat dome that constitutes the bottom of Kilauea Crater. If the Halemaumau lava column were to sink bodily, it would slice in two, vertically, each of the three slag heaps southwest, southeast, and northeast, carrying down the inner halves and leaving the outer halves as eminences in the new rim of the pit. The three lava heaps were over the "wall crack" of the pit. The wall crack is at the contact of lava column and ring wall. There was a glowing cone, with its incandescent interior a cavern, hung with stalactites (Pl. 7), at the east, and other detailed features of this kind, with small pits, grottoes, and spatter heaps formed from time to time in relation to the vents at flow sources. Thus on February 18 there were 12 flaming cones and 4 lakes.

RAPID CHANGES OF OVERFLOW, FEBRUARY 1919

The last week of February produced mass swelling of the lava column, eruptions of standing fountains of melt, and extended overflows east, southeast, and south; the lakes as well as the slap heaps overflowed; all the lakes stood as ring-shaped basins above the old rim level of the pit; and from collapse of the cones there were now six lakes. The year 1919 was to be a culmination of overflows from Halemaumau.

NEW BORDER PRESSURE RIDGE

Again there was renewed mashing upward and outward of the old Halemaumau pit rim southeast, south, and east, so as to make a pressure ridge from 8 to 15 feet high, with an elephant's-back curve on the side away from the pit. The ridge was 20 feet wide in places and resembled the up-crushing of the rim southwest and north in February and October 1918. The three most used surveying stations were destroyed, but the net rise of the eastern side of the lava column was measured as 10 to 15 feet.

The first week of March 1919 developed a cone steeple of spatter building 12 feet high at the northeast heap and overflows south and east. This flowing continued with swelling of the floor and with high gas pressure marked by hissing cones and spraying grottoes, and subsidence followed after the equinox. Then there was enlargement of all lakes and lowering of liquid lava 15 to 20 feet. This was accompanied by some merging of the lakes by breakdown at the end of March.

BENCH MAGMA LOCKED TO PIT RIM

The beginning of April 1919 the floor with its tower and heaps had sagged about 10 feet, but the floor appeared to be more rigid than when it was covered with crags. Probably this was because the slag heaps around the edge, with their overflows overlapping the outer Kilauea floor, locked the bench magma to the rim of the pit.

Early in April the liquid lava recovered (Pl. 31a), rising 10 feet per day in the lake cups at first, then making flows from the tower region of the northeast heap, of heavy bulbous pahoehoe lava, inward toward the low part of the Halemaumau floor at the north, between the north lake and the only part of Halemaumau pit wall that was still unburied.

UNEXPLAINED PATCH OF INCANDESCENT LAVA

On April 11 a patch of incandescent broken lava, on the solidified summit floor of the northeast heap, kept glowing for several days without noise, solfataric stain, or visible flame. There was no odor, and the place had exactly the appearance of a bed of burning charcoal 2 feet square, of cherry red heat, abruptly bounded by shells of nonincandescent lava of the same kind. The only apparent explanation was slow seepage of burning gas, oxidizing the rock above some gas cavity below. This kind of glow is akin to what had been observed before (*see* March 15, 1917), and large patches of rusty lava, hot enough to ignite wood, remained for years at the flow heap Mauna Iki, where the 1920 Kilauea flows originated.

OUTFLOWS OF HALEMAMAU FROM RIM CRATERLET, MARCH-APRIL 1919

In accordance with habit the moderate flowing of the first half of April 1919 gave place to mass swelling the third week, ending in strong overflow that broke through the south pressure rim of the edge of the pit and produced the longest and most liquid flow of 1919 to date. This covered the trail and reached the road terminus and was the third of the year that had extended about half a mile from the Halemaumau center, to the south and east. The dates were March 4, March 12, and April 17, the last from an eccentric tumulus southeast of the Halemaumau center. The extensive flows which had poured to the northwest from the center of the pit had been confined within the old pit wall. This border action suggests the craters on the moon, with their peripheral pits.

TELESCOPE MEASUREMENT REVEALS HORIZONTAL PRESSURE, APRIL 1919

Halemaumau as seen from the Observatory (Pl. 25) was now a smooth curved dome 1200 feet across, rising from the base of the low northwest rim cliff remnant to a height of 50 feet above the general level of the former rim. This dome fell off abruptly as an escarpment 40 feet high on the southeast at the pressure rim. Apparently the pressure had been bodily eastward overriding the pressure rim, itself an upcrushed arch of matter, squeezed back at the southeast edge of the former pit. Known landmarks on the pressure rim, like the southern cones, measured on a telescope scale in profile from the Observatory, had moved east within a few weeks. Along with this had gone the mashing up of the slabs of rim rock, with an angular rotation, from horizontal to vertical and beyond. The old edge of the pit, facing west, had been raised *en masse*, then had been mashed until it fell backward in a talus, and the upper part of the cliff scarp was now the cross section of the inner live lava layers, where the new pit floor had been lifted clear.

POSTAL RIFT FLOWS

April 20, 1919, inaugurated a series of big flows from cracks outside Halemaumau in the Kilauea floor at the north (Pl. 46). These flows were destined to continue throughout most of the year and are collectively called the Postal Rift flows. The crack marked the ancient rim of Halemaumau prior to 1894 (Pl. 9b).

Tumescence extended to the rim of Halemaumau west and north, tilting the west station 4.5° to the southwest and the north bench mark 8.5° to the north. The latter was lifted approximately 8 feet within a few days. This assisted the mountain uplift (Part 4, Wilson, 1935).

At noon April 20, liquid lava welled up in a standing fountain through the cracks of the Postal Rift west of the small solfatara crater known as Pele's Kitchen. There was no seismic disturbance. The place was approximately 790 feet north of the pit rim. Great volume of lava flowed rapidly in rippling liquid cascades, so that in 2½ hours the front was 900 feet from its source. There was a small earthquake shock instrumentally recorded in the afternoon, and at 7 p.m. two small cones had been built at the source of the stream, which was pouring north-northeast, straight toward Perret's steam cone (Pl. 8d) in the north corner of Kilauea Crater, widening out in laurel-leaf shape, with moderate fountaining at the vent. The Halemaumau lakes rose and increased their gas pressure, and the tumescence of the bench magma lessened.

The front marking rate of advance of the Postal Rift flow was as follows: April 20, 3 p.m., 0.4 miles, April 21, 10 a.m., 0.5 mile, April 22, 11 a.m., 0.6 mile, April 23, 10 a.m., 0.9 mile, April 24, 11 a.m., 1.2 miles, April 25, 12 noon, 1.4 miles, all distances measured from the center of Halemaumau.

May 1919 was preceded by a short sinking spell, so that the Postal Rift flow came to rest. April 29 strong rising and flowing was resumed, the Postal Rift flow lengthened until its front was in the extreme north corner of the Kilauea floor, and it spread sidewise in many places along its whole length, flowing against the northern end of the Uwekahuna wall and reaching a distance 1.6 miles from the Halemaumau center by May 3. The tilt of the northern bench mark on the edge of Halemaumau, and of the west bench mark, suggested an arching of the north rim of the pit, over a conduit leading to the Postal Rift flow, as well as a pushing up of the ground away from the center of Halemaumau (map, Pl. 84).

The flow widened out at the source region so that the extremities of its two lateral arms were 0.7 mile apart, shaped in plan like a bird with out-stretched wings, between the base of Uwekahuna bluff and the depression west of Little Beggar. Meantime there had been other flows southeast and southwest.

The north bench mark was lifted more than 10 feet above its original position. This was followed, however, the second week of May by subsidence of the liquid lava of the lakes, with collapse and lowering of the broken ground between the eastern lake and the north lake. There was also a southwest lake connected by a channel with the eastern or main lake. The three lakes were arranged within the swollen dome of overflow shells as cups in clover-leaf shape. The lowering did not stop the extension in all directions of the Postal Rift flow, along with development of swollen domes in its frontal lobes.

DEVELOPMENT OF *SCHOLLEN* DOMES

This development of so called "*Schollen*-domes" was interesting. Tumuli would swell up, about 15 to 20 feet across and 5 to 10 feet high, in the frontal leaf-shaped parts of the Postal Rift flow. An individual dome would form within a day or two. Usually lava would well up through cracks in the roof, often very pasty, solidifying as heavy lumps with rough "shark-skin" surface and even with formation of aa. Aa was rare on the Kilauea floor but had been observed in parts of three different flows since February 1918.

The apparent explanation for schollen-dome swelling is that the crust and margins of the flow lobe solidify, a temporary stagnation makes the inside lava pasty, and a revival of pressure finds that swelling is the path of least resistance. The forces inducing pressure through the lava tubes are hydrostatic, aided by gas effervescence at the source and by weight of heavy fields of flat crust where the cavernous space filled with lava has too flat a roof to be supported as an arch.

DESTRUCTION OF PERRET'S CONE

The third week of May 1919 produced a ceaseless torrent of the lava of the Postal Rift flow through tubes to its northern fronts extending itself generally over the northern quarter of Kilauea Crater, piling up along the base of the western wall and obliterating the vapor vent (Pl. 8d) known as Perret's Cone. Through all this the surface of the Halemaumau lava column lowered about half a foot per day, and a block of the dome on the south side of the central pool May 20–21 sank 20 feet; it slumped into the lake and made normal talus slopes at the lake shore, at flat angles of rest, indicating that the lake had a shallow bottom, as usual. The subsidence at the end of May took the form of collapses of cones, which broke down over voids below, smoke increased from crevasses in the center of Halemaumau, and the Postal Rift flow showed somewhat diminished volume.

TORRENT OF LAVA IN TUNNEL

On the north side of the cone source (Pl. 34a) of the Postal Rift flow, two windows in the roof of the cavern leading from it revealed a brilliantly incandescent cavernous space where, about 12 feet down, the orange-colored melt flowed northward in a majestic torrent. Under the cone, one could see a standing fountain feeding this flow. This was the well-spring which ceaselessly fed the ever-pushing fronts 1½ miles away, and by looking downstream through the window one could see the river pour northwestward in a tube, where blue fume rose through cracks in the roof of hardened flow lava. The entire lining of the tube was at bright-orange heat, and the gases emerging were not particularly sulphurous. This tube had been filled like a sewer when the flow pressure was at its height, and its partial evacuation was evidence of decline in volume of lava.

SUBSIDENCE OF JUNE 1919

June opened with continued subsidence of lava at Halemaumau pit, increasing moderately, while the Postal Rift flow under the north wall of Kilauea Crater was beginning to progress from that region eastward, toward the trail under Volcano House. The central floor of Halemaumau southwest was now 80 feet above the 3700-foot contour, which represents the former level of the north rim of the pit. The main lake inside Halemaumau was about 45 feet below this southwest block.

The subsidence in Halemaumau finally revealed a lava cascade, whereby the liquid of the main lake poured over a submerged ledge, into a fiery pot, at the base of the northeastern marginal cliff, at the border of the lake. This cascade was occasioned by the usual faster sinking of the melt at the sinkhole of the convectional circulation, the inflow conduits continuing their work so that the lake levels remain relatively constant, even when such a draining cascade continues for many days. This fiery Niagara the second week of June persistently poured into the gulf as a violent torrent for a week, yet the lake feeding it rose at times in relation to its own banks (photographs in Haw'n Volc. Obsy. Bull., August 1919).

About the June solstice, the lava floor of Halemaumau had continued to subside a foot per day, but the main lake started rising half a foot per day. The dense steamy fume which had been rising from the central chasms of the Halemaumau dome diminished. The first cessation of the cascade at the lake edge was observed June 18, 11 days after it had commenced. The volume and speed of the Postal Rift flow decreased.

Just at the solstice, June 20–23, the prism of hard lava surrounding the lakes subsided sharply, so that the gentle sag of the surface of the dome became a sinking cylinder; the edge of the former pit asserted itself as an in-facing cliff, the northeast tower fell into the pit beneath it, where a new circular pool of lava formed. The crisis of release of pressure made the liquid lakes froth up higher in their cups, accompanied by spatter building at the border fountains, and there were new wall-crack ponds. The Postal Rift flow continued to spread. The subsidence of bench magma was nearly compensated by the relative rising of the liquid.

In the glowing interior of the Postal Rift source cone slender wormlike stalactites had formed, hanging motionless and brilliantly incandescent, added to by slow accretion of fused material from the walls, through gas melting. The standing fountain under the cone was like a cascade feeding the flow, seen from the window of the cone, and spouting thus about 15 feet below the surface of the ground. The slow, steady river of melt, 20 feet farther north, streamed away northward, with drawn-out gas bubbles bursting the surface. At night the glow lines of the flow, under the northern Kilauea cliffs, increased in brightness.

JULY 1919 ENDS FIRST POSTAL RIFT FLOW

At the beginning of July the sinking of the bench magma decreased, but the lakes went down rapidly. The Postal Rift flow ceased moving, and by July 4 only a little dull red glow could be seen in the hardened flow of the bottom of the Postal Rift tube at the window.

CHANGED PIT TOPOGRAPHY 1919

The second week of July produced much collapsing of the Postal Rift flow tube, and subsidence at Halemaumau decreased. There was some recovery of the liquid lakes. The inner cliffs around the lakes were 28 to 40 feet high on July 12. The measurements at this time, when Halemaumau revealed a new cliff edge, showed remarkable changes of the rim, remnant from the dominant upward thrust and overflooding of the pit at the southeast, in 1918 and 1919. Before that the highest wall of the pit itself had been at the north and west; now the lowest walls were there, and the west station was the only older bench mark which remained at nearly its former attitude. The new north flag station, almost directly over the site of the old stone shelter hut (buried under overflow layers), stood 18 feet above the ground level of 1917 at that point, although it was now the lowest rim station. All through the first half of 1919 the southern lakes were highest, the middle lake intermediate, and the north lake much lower. This means that three wells close together, parts of the same lava column, maintain different vesiculation levels.

After the middle of July rising in Halemaumau became general though slow, with the lakes quiet, dull, and crusted. About July 21 began a sharp rise (Pl. 30c) carrying up both the foaming lakes and the semisolid bench magma. There was no revival of the Postal Rift flow.

TRANSIT MEASUREMENT OF LAVA TIDES

At this time an investigation was begun (Pl. 32) whereby five men measured with transit every 20 minutes, night and day, for a month, to discover whether there is a daily tidal surge in the bench magma and liquid lava. The plan carried out was to locate the transit shelter on the inner floor of Halemaumau, near the north bank of the north lake. Markers were placed on the Halemaumau dome and at the west station outside of Halemaumau with a paint mark visible in daylight and a lantern at night. Then a series of grottoes at the edge of the lake were located by angles; the combined readings of horizontal and vertical angles, using the fixed west station as datum, would exhibit the fluctuation of the markers on the dome of magma, and the grottoes in the lake of liquid lava. Meantime daily surveys were made of the transit position and elevation, from the rim of the pit as base. Occasionally the west station was checked as to its uplift, from bench marks on the rim of the greater crater.

From the beginning of this work strong and continued rising gave unexpectedly pronounced changes of angle in the measurements. The index error of the transit was continually read, and the transit leveling repeatedly corrected. This furnished data amounting to several degrees for the strong angular tilt of the ground under the transit standing on the bench magma. The ground domed up quietly and continuously; there were no shocks of earthquake to the transit men, in camp, actually on the top of the lava column; the entire movement proceeded like rising dough. There were creakings and snappings in the outer old wall rock of the pit.

August 1919 opened with the lava column rising 4 feet per day. This uplift culminated in outflows north and south, the northern one breaking through a vent in the Postal Rift area and pouring a few hundred feet northward near Pele's Kitchen. The continuous measurement of the lava tide exhibited striking fluctuations in level of both bench magma and lake magma; especially on certain groups of days these showed rhythmic diurnal risings and fallings.

TUMEFACTION MEASURED WITH CAVERN SEISMOGRAPH

Tumescence of the Kilauea floor, outside of Halemaumau at the north (Pl. 34c), again occurred just before the new Postal Rift outbreak, so that near a seismograph in a cavern there were crunching noises and falling rocks July 26–27; this instrument revealed excessive tilts, sometimes sudden, away from the Halemaumau center. The south pressure ridge also started moving and crunching again, and a lava flow emerged there.

SWELLING AND OUTFLOWS CONNECTED

August initiated a merging of the four central and southern pools. Overflow necessitated removal and replacing of the transit shelter, without interruption of 24-hour measurements. The outer rim of Halemaumau was rising on all sides. By the middle of August the rate of rising of the bench magma slackened, but the flooding of liquid lava increased, and outflows were numerous. The second Postal Rift flow continued. Emerging from a cone now about 8 feet high, with gas spiracles on its crest, this flow had now extended to the southwest as well as to the northeast and had filled the seismograph cavern. The lakes themselves overflowed, and as usually each pronounced spell of localized overflowing was preceded by rapid localized swelling.

The third week of August produced a pronounced lowering of the lava column, simultaneous with the most voluminous flow (August 16), spouting from new cones of the Postal Rift to the west of the earlier outlets. This flow swept in a few hours across the Kilauea floor to the southwest wall of the greater crater and then spread northward, with fresh gushings every evening.

END OF LAVA TIDE INVESTIGATION

At noon August 18 the lava-tide work ended after 28 days of continuous measurement (Jaggar, Finch, Emerson, 1924; Brown, 1925). The ground under the transit shelter was so inclined to the north that the slope showed in the tent poles, and the sleeping cots had to be blocked up to make them level. The cracks in front of the shelter were hot enough to boil water in a few minutes, and the tent poles repeatedly caught fire from the hot ground.

At the end of August the intense fountaining at the source of the Postal Rift flow ceased, and the crusted flow continued to pour through its underground tube. The lava column in Halemaumau was essentially stationary.

SEPTEMBER PRELIMINARIES OF CRISIS

In the first week of September 1919 there was little change in the appearance of the lakes and crags, and slow subsidence set in, so that on September 10 there was a cascading from both the north and main lakes toward a central sinkhole. The Postal Rift flow continued, with the source cone hissing and developing yellow sulphur. The rim flags of the pit showed a lowering of 1 to 3 feet, after the previous tumescence.

At 5:20 p.m., September 14, a prolonged, strong, twisting earthquake was felt generally on Hawaii, damaging the Kau section; chimneys fell, and walls cracked, indicating intensity No. 8 Rossi-Forel. Objects were thrown down in Hilo. Rock slides occurred at Kilauea. The seismographic record of movement of the ground continued for over an hour. At Hilea, east of the south end of Mauna Loa, there was a swarm of felt after-shocks, gradually decreasing for 22 hours, suggesting an earthquake of unusually deep origin. There was a second strongish shock at 3:37 a.m., September 18.

These earthquakes between Kilauea and Mauna Loa, just before equinox, suggested a volcanic crisis of importance. The Postal Rift flow increased. At the time of the first earthquake there was strong north and east tilt at the Observatory, reversing the previous southwesterly tendency.

ALIKA FLOW FROM MAUNA LOA

The seismic crisis was explained by an outbreak of Mauna Loa about 3 miles south-southwest of the southernmost pit of Mokuaweoweo, elevation 11,000 to 11,500 feet, at 6 p.m., September 26, 1919. Probably a deep rending open of the Mauna Loa rift system produced the earthquakes, and the rising wedge of gas-charged melt finally attained release.

SYMPATHY OF KILAUEA WITH MAUNA LOA

The Kilauea lava column responded with great increase of volume from the Postal Rift source cones, reviving the incandescence of the flow, as seen at night, all the way from the source cones to the front, and producing surface spouting from a new oven that opened on top of the flow a few hundred feet west of the source vents. On the day of actual Mauna Loa outbreak there was irregular disturbance in Halemaumau, with reversed streaming in the main lake, strong fountaining, and sinking bench magma, but all this had begun 3 days before.

DEVELOPMENT OF MAUNA LOA ERUPTION, 1919

The Mauna Loa outbreak was seen as brownish, cauliflower gas volutes rising in the evening from south of the summit of the mountain, with chocolate-colored edges against the light of the setting sun, and a smoky aspect in marked contrast to normal clouds. The lower billows were terra-cotta in color, illumined by the lava fountains beneath. There were two distinct columns, as in 1916, a mile or so apart. The crest of the cloud stood 7000 feet above its base at 6:30 p.m., the northern column the stronger of the two, and both a bright orange red in the evening light. This preliminary eruption quickly waned, and by 7 p.m. the pile of vapor had ordinary cumulus form, the glow of the eruption lasting until midnight. There were fresh small flows around these orifices which were later identified. The glow was no longer visible at 3 a.m. the next morning. The Kahuku ranch occupies the long southwest rift slope of Mauna Loa.

The final outflow from Mauna Loa, 2 days and 14 hours after the upper outburst, appeared at 1:45 a.m., September 29, from a vent on a southwest-trending rift line in the Kahuku lands, about 7700 feet above sea level, and 11 miles down the mountain from the point of the first outbreak of September 26. The new lava flood quickly descended the steep forested slope of the west side of Mauna Loa and in 24 hours reached the sea, traversing a curved path 14 miles long. The progress was about 1 mile per hour in the steep forest and 0.6 mile per hour to the sea. A flowing narrow torrent within its aa fields then developed and continued, cascading into the ocean and sending up clouds of steam and killing fish.

SOURCE FOUNTAINS OF MAUNA LOA, 1919

The source fountains were visited by three expeditions from the Observatory during October. Great fountains were spouting continuously along the fissure for 1000 feet like a wall of red flames. In detail they were made of light crumbly incandescent material, yellow when it shot up, red when it came down. The noise was a roar like surf, made by gas rushing through a froth pool filling the rift. Northward from the large fountaining pool, the fuming vents lay on a rift line a mile up the mountain, the smoke and lava jets there becoming smaller. Average spray jets were 150 feet high, exceptional ones twice as much. To the west, the whole upland country was covered with glowing and flowing lava fields. The spatter ridge at the great fountains, seen from the end, stood up as a narrow shell confining the mighty spurts, its height about 100 feet. The fountain jets sprayed up continuously half again as high, the glowing soft fragments eternally pounding down upon the rampart, plastering it with the new matter and gilding it with a mottled fiery pattern of big clinkers that rolled noisily down the outer slope. The outlet through the rampart was in a gorge 40 feet wide, where the main lava flow rushed like a torrent from the sluiceway of a dam. The current shot away in a fiery river 18 miles per hour, first straight for 300 yards to the south, then bent and plunging over a fall into a brightly glowing abyss beyond.

The stream appeared shallow with many standing waves and bright grottoes. The fumes had an oppressive foundry smell, with sulphur added. A glimpse into the fountaining foam lake, obtained by a dash up the rampart, revealed heaving foamy lava 20 feet below the edge, with the fountaining belt 100 feet wide standing over the rift zone, on the eastern side of a crescent-shaped lake.

Next northward there were 11 spraying and flaming cones, making violent explosions and doing much spilling over and rocketing. The "Growler" would awaken spasmodically and become noisy with gas-engine popping. The noise of the main lake was compounded of rumbling and bombardment. All together, the traffic and metallic clangor in the hubbub, gave one the sensation of looking down upon a factory city.

The source flow developed a fork. The fragments in the fountains were basaltic pumice, which changed color as they cooled from 1100° C on rising (orange), to 800°C on falling (dark red). The rampart caved in. Flames were bluish green to violet. Over the great fountains were banners of nearly colorless transparent flame, 200 to 300 feet higher than the fountains, surmounted by salmon-colored condensing fume. A flutter of yellow-red marked these flames, and there was much bright green where the yellow reflections on fume streamers blended with the blue flame of burning gas. It all suggested the prominences of the sun.

NIGHT BIVOUAC ON MAUNA LOA

The whole landscape was illumined, and with night air temperature of 45°F the heat was comforting 700 feet away. Now came heavy boomings. At 9 p.m., September 30, three belts of the rift were in violent activity, there were fountain jets by the hundred, flanks flooding, a golden sheet of overflow, a lava geyser, and a bright-line pattern of black and gold spurts like Roman candles; a new river of slag poured by to the southward, and a veering wind brought pungent sulphuric acid gas making the eyes smart, when light pumice lapilli showered our bivouac. The flow was burning bushes, the Growler was no longer noisy, a heavy gas haze hovered low, a white butterfly strangled by the gas lay dying on a bed of pumice.

All the flows near the source rift were rough pumiceous pahoehoe on the surface, with aa sprouting clinker in places. The development of continuous clinker in the flows took place within a mile from the source. The rapid cooling of the Mauna Loa pumiceous lava makes the fountains scarlet in daytime, whereas a bright orange is the rule at the Kilauea grottoes. I got the impression that the Mauna Loa heat was greater in volume, but that the temperature in detail was lower. There was no such quantity of Pele's Hair found near the Mauna Loa vents as at Kilauea.

The color effects at sundown, at the rift source on Mauna Loa, were gorgeous. Over the scarlet fountains rose sheets of red and green flame topped with lilac fume, against a murky green or blue-gray background. Above rose the great buff-colored volutes of cloud, with individual billows coffee-colored or brown. All this was backed by an outer sky of deepest cobalt blue, with normal distant horizon clouds of pearly gray.

SECOND VISIT TO MAUNA LOA SOURCE, 1919

These first visits to the source region of the Mauna Loa flow of 1919 were made about October 1 (Pl. 59a, b, c). A second visit a week later, also from the eastern side, showed that the activity had built up the cones so that the eastern side of the southern or Alika cone was now 150 feet high, with fountains shooting up irregularly 50 to 100 feet above the rampart, while a string of active cones had been built farther north. Here the caldrons of the middle zone were throwing up geyser jets 200 to 400 feet high, sometimes subsiding to growling activities which made deep thudding detonations. A high pot was overflowing its lip sluggishly while flame burst through the crust. Overflooding was incessant until the fountaining heap became a radiant golden overflowing chalice. North from the middle zone of greatest activity, there was a line of vents showing a chimney 15 feet high with blue flame, a small cone sending up rocket sprays, and the former "gold" cone now about 30 feet high, with a flaming and spraying fiery filagree. Farther north there was one idly flaming and fuming cone, and vapor rose from the rift ridge and from fresh flows east of the ridge, for a width of about 200 feet. Beyond to the north was a line of fuming cracks and some cones in the direction of the summit.

The lake inside the Alika crater, seen across glowing beds of pumice like hot charcoal, had a granular surface dotted with black, heaving in very liquid fashion, with fountains playing up on the east side to heights of 100 to 150 feet. A spatter island stood in the middle of the lake, the usual gigantic banner of flame played above the whole line of fountains, which had a straight rampart along the rift line proper, and the western border of the lake was irregular.

SWAMP OF GLOWING MELT

From the high rampart 90 feet above the general level, an observer saw the Alika flow rushing off to the southwest across the upland in a meandering river of fire with a piling-up effect at the bends; as before there were standing rapids, as a distinctive feature of the stream, where it flowed in a straight course near the source. The stream was about 40 feet wide, the surface was granulated with a pattern of black blotches, darkest along the middle part of the current, and here and there the banks slighly overflowed. Beyond the river there was a field of sluggish-flowing lava, appearing to be a vast puddled area. A whirlpool formed in one place with double swirling and spurting as though a tornado had caught up the surface fluid. A branch current near the south edge of the fiery swamp occupied a definite channel joining the Alika stream, like the distributaries and cutoffs of a river delta. The hardened lava near the source crater was pahoehoe, though the granulated surface of the Alika river looked as though it would solidify as aa.

LAVA FOUNTAINS 500 FEET HIGH

The night of October 10, 1919, a new flow developed from the middle vents, which swept to the south and southwest down the east side of the rift cones, and the former main lake in the cup of the Alika cone to the south became inactive about 4 a.m., October 10. The middle fountains of the series along the rift became one gigantic line of geysers of fire, with maximum jets estimated 500 feet high. This line of fountains extended for 400 feet through all the cones and pots of the middle zone. The southernmost of these overflowed in a torrent from high rhythmic surges of the craterlet pond, filling a saddle and overflowing westward, as well as feeding the flow on the east side. No earthquakes were felt, but the deeper explosions made concussions. The quality of the fountaining was frothy, and the upward jets were shredded, but the concentrated force of the eruption, in smaller vents, made the intensity much greater than on October 1, and 400-foot jets were common. There was a continuous shower of pumice during much of the night, some of the fragments an inch in diameter, light greenish-gray, frequently with drawn-out threads of Pele's Hair attached, and this material must have fallen many miles to leeward during trade winds.

Down the mountain there was much pooling of a wide flood of lava north of the Alika flow, which had stopped visible motion at the road crossing, after the Alika source cone stopped functioning. There appears to have been a culmination of intensity, in fountaining and flowing, about October 15, when there was also a seismic maximum, registered by instruments at Kilauea. The northerly flows spread into the forest but did not reach the road.

A last expedition to the source, from the western side, October 25, discovered that a northern cone had developed with a flood pouring westward. This had fountains spurting 400 feet into the air from a crater that was an open horseshoe, with a lava cascade 15 feet wide pouring from an opening northward. The cone was 200 feet high, and the lava channel extended miles away as a gorge; this was bordered by other lava spread out as hot fields on each side, themselves in motion and incandescent beneath the surface. Their thickness varied from 40 feet near the cone to 5 feet at the edges of the floods. The whole upland plateau west of the rift line was covered with fresh lava which had been repeatedly rearranging its channels. The channel lava rose and fell from time to time, backing up and overflowing by some mechanism of viscous accumulation. The cascades in the channels made spots of brilliant glare on the fume above, and occasionally loud detonations were heard, caused by explosion of mixture of air and carbon gas from vegetation, in old caverns adjacent to the hot flow. There were odors of spicy sulphur.

The rift line was a distinct single crack trending south-southwest, and the cone craters were developments due to lava and gas rising through this crack after September 29, 1919. The alika cone at the south came first, and in the course of a month the lava deserted that vent, sealed the rift from below in the uphill direction, and built up the northern cone half a mile away. Along this half mile were distributed the big fountains. North and south the 1919 crack continued for more than a mile in each direction, marked by small cones. When the middle belt had quarried out holes apportionate to the eruptive energy, the small vents sealed themselves. Deserted portions of the rift were not incandescent and full of obnoxious gases, but merely a line of small holes 1 or 2 feet in diameter with smooth black lava on the sides, red stalactites inside, and some warm air rising and smelling faintly of sulphur.

On the morning of October 25, the flows on the east side were all dead, the line of cones was now a ridge 200 feet high in places, banked by flows and pumice for nearly half its height; for the three main places of activity, south, middle and north, the southern cone was dead, the middle crater would fling up a fountain above its rampart occasionally, and the great north cone was very active.

Over its high summit lip the fountains would fling their red crumbly fragments, which fell in an endless avalanche of fire on the steep outer slope. The wind here set up small tornadoes and picked up the light pumice in violent, noisy whirls. The fountains of the inner bowl, made by gas rushing continuously up through the lava lake, consisted of an endless succession of big jets, ever changing their direction and angle, and not necessarily vertical. There was the deep rumble of the gas and the surflike noise of falling, occasioned by the enormous showers inside the crater itself.

The avalanches outside made distinct individual crashes. South of this cone in the saddle between it and the middle crater, a smaller cone emitted dense smoke.

EXPERIENCE OF MAUNA LOA SOURCE FOUNTAINS

Trudging through pumice knee deep and excessively hot, I climbed the north spur to photograph the fountain. On the other side of the spur, which was the east end of the enclosing horseshoe ridge, open to the north, lay the fountaining basin of golden froth with its gigantic waves surging forward to the cascade outlet. From under the back wall of this cup rose the geyser of fiery fragments, 200 feet above the level of the top of the spur, the pieces bright red hot and very porous, from 6 inches to 4 feet in diameter. The hardened lava is efficient as an insulator against heat.

The sensation of looking up at that incessant towering curve of rising and falling bombs, and calculating its angle, with the heat almost unbearable and the noise deafening, was an unforgettable experience. The interior of the basin was like a titanic open goblet of fiery liquor, foaming in scarlet surges, these being impelled continuously forward by the geyser jets behind, the flood lifted by the jets losing its liquid aspect almost instantly, and the expanding gas within the jet giving it the appearance of loosely knitted worsted, but each shred was shining glass when it reflected the sun's rays. The frothing surges were liquid as beaten foam, bubbling and seething, but the torrent quieted down quickly and formed black skins at the outlet through the sluiceway.

Examination of the bottom, by walking across the now dormant southern crater, which had been frothing on October 1, revealed an inactive basin 1000 feet in diameter and 300 feet deep, with the western wall much the lower. A break in the southwest wall showed where the channel of the Alika flow had been. The bottom was smooth pahoehoe plastered over large balls, which resembled the rafts seen in the flow at the roadcrossing. The edge was traversed with cracks emitting scalding hot vapor. As the inner surface was 100 feet deeper than the general level of the outer country, that depression represented collapse on the rift line.

The activity waned after October 26. Exploration of the western lava field showed a channel of flowing slag less than 100 feet back of the north edge of the field; the stream lost speed rapidly from east to west, moving 15 miles per hour near the source, 10 miles per hour 2 miles west of the source, and 3 miles per hour at a point 4 miles west. The channel narrowed from 25 feet to less than 15 feet. The stream made a mild rippling sound like running water. Large rafts would jam at a bend, block the current for a few seconds, then the liquid portion would percolate through the cracks and disintegrate the rafts, and the masses would give way suddenly, making a flood. The raft boulders were red hot and cheesy and were carried along and rolled over and over. The lobes of the front of the general lava field crept forward by internal push, at rates varying from 2 feet per hour to 200 feet per hour; this depended on whether the lobe was immediately fed by a distributary channel of the liquid stream or not.

Small explosions were heard in caverns. Four miles west of the source there was a sullen, noiseless, red river, covered with rafts and black chunks, always spilling northward, sideways and in one direction. It was as though the river bed slid downward sideways, on the aa lava field of its own making. Bushes burst into flame;

a branch flow came right out of cracks in the ground where a lobe had found access to an old tunnel; another branch poured into an old pit; and much coal gas was perceptible, occasioned by the burning vegetation. The flow gas was merely sulphurous, and even the source fume was not different from that of Kilauea. This was remarkable, for on October 9 the gases had been strong with sulphuric acid (SO_3) and often quite irrespirable. There was always much of the foundry smell.

After November 11 the only evidence of activity over the source rift region, as seen from a distance, was an occasional development of convectional cumulus cloud tending to mushroom form.

MAUNA LOA FLOW NEAR SEA

When the source vents opened about midnight September 28–29 near the 8000-foot level, the flows spread west-southwest, reached the steep forested slope, crossed and destroyed the belt road as a stream of aa lava about 100 yards wide in the Alika land at 9:30 p.m., September 29, and at 4:30 a.m. the next morning plunged into the sea over a narrow platform of old lava flows, backed by a bluff and faced by a low cliff at the shore. The source was about 14 miles away, and the flowing into the sea continued for 10 days.

There was a succession of short-period, shallow tidal waves set up by the ocean disturbance during the period of flowing into the sea, the range of rise and fall from 3 to 14 feet, with maximum on the third day of the flowing, and largest amplitude at places nearest the flow delta. Noises under water, heard from boats, were of seething and of tapping concussions. The uprush of steam where lava and water made contact built up a large cone (Pl. 60a) of rock fragments and black sand. The lava rafts which swept into the water bobbed up, made surface steam, and floated at first, buoyed by hot gas. Lightnings appeared in the steam column, and there was much muddying of the water and killing of fish.

At the road crossing at 10 a.m., September 30, the lava field was black aa with glow and flames all over the surface, the flames doubtless from the forest buried beneath. This was about 1600 feet above sea level. Across 500 feet of black clinkers a foaming torrent of liquid lava made a noise like running water, with speed estimated at 5 to 10 miles per hour. Big raft blocks, red below and black above, were carried down the stream, either smoothly or rolling over as though striking on the bottom.

At the seashore there was a 15-foot wall of glowing aa lava, and when one stood on a shelf of the older cliff it was possible to look down into water boiling hot, where blocks of incandescent lava were tumbling into the sea, and the dense steam vapor fogged the view of the main torrent. The sea water was bubbling, and dead fishes of many colors floated in it. A column of vapor rose from the lava channel at the water's edge, and 50 feet out to sea the surface was dotted with small jets which would occasionally form a whirling steam spout or tornado, a foot or two in diameter, rising from the water so that its vapor joined the cloud above. Close to shore showers of small rocks were jetted up 15 or 20 feet, each projectile followed by a tail of vapor.

At the road crossing next day, October 1, at noon, the channel stream was lower and had narrowed from 250 feet to 125 feet. The lava field was about 1000 feet wide, and there was coal gas, producing dizziness and shortness of breath in visitors. The rafts were larger. Southerly breezes on October 4 made all the eastern Hawaiian Islands smoky. Two additional short arms of the flow through the forest had crossed the road north of the first arm, and this extension of new arms to the north and farther up the mountain continued throughout October. The length of roadway destroyed increased to 2000 feet. The lava channel was 40 feet wide, and the three impressive features of the molten torrent rushing through the gorge (Pl. 59d) were the noiselessness, the standing waves, and the occasional overflows. The visitor could stand on the hot lava field beside the torrent. The uphill slope of the steepest part of the channel was about 8°. The stream was bright red, with darker blotches of rafted material in the middle and incandescence along the banks.

All along the course of the stream were standing waves from irregularities of the bottom which threw the torrent into undulations, from 50 to 150 feet from crest to crest.

There was a slight swishing sound, occasionally becoming a rumble when the lava was rising in the gorge. Generally the liquid surface was 10 or 15 feet down, but it took only a few minutes for it to rise and brim level with the banks, and even to overflow. Downstream there was a short tunnel bridged over by previous accumulations, and these sudden, unexplained risings may have been due to the blocking of such tunnels by accumulations of rafts. The largest raft blocks were 10 to 12 feet in diameter, and they moved about 11 miles per hour. At the edge of the outer lava fields there were rows of trees, fallen but not burned.

The effect in the lava stream was as though the bottom were everywhere at shallow depth, and this bottom was itself semicongealed or bench magma shifting downhill more slowly than the liquid river on top.

Visible flowing stopped in the Alika channel at the road level on October 10, and as the source vents shifted northward new flows invaded the forests north of the original Alika stream. The longest of these was in Kaapuna, and it stopped 4 miles east of the highway. As the whole country is forested (Pl. 60b) and its shape a steep elephant's-back slope, along which the road follows a contour about a third of the way up between the sea and the timber line, the situation in South Kona, created by this uncertain condition of the lava menace above, was critically dangerous for the inhabitants.

The middle of October produced the maximum of the source eruption, with upland pooling of many tongues of flow about the upper limits of the forest and occasional invasions of lava flows into the timber. October 16, there was excessive noise at the source region, much of it occasioned by gas explosions in old caverns.

In general, the Mauna Loa eruption of 1919 dwindled the last half of October; fields of lava were stagnating at the western brow of the upland and making progressively shorter westward arms from sources progressively northward from the Alika source cone. No considerable glow over the source region was observed after November 5, and the motion of flows gradually ceased.

EARTHQUAKES ACCOMPANYING MAUNA LOA FLOW, 1919

At the beginning of October just after the outbreak on Mauna Loa, no unusual local seismic movement was registered at the Kilauea station. Fourteen shocks in 6 days were registered beginning October 5, all but two of them feeble.

This seismic activity culminated on October 14 in a total of 18 shocks in a day, and thereafter the frequency declined, though occasional earthquakes of large amplitude indicated increased seismic intensity. The seismographic distance accorded with that of the Kahuku rift at the Alika source cone. Four shocks were felt at Hilea, just east of this region, between October 11 and 17. Tremor increased somewhat at the Kilauea seismographs, but as there was tremor anyway from Kilauea activity its relation to Mauna Loa was not determined.

Toward the end of October the number of shocks registered daily decreased, though individual local earthquakes had greater intensity. There was a considerable revival of frequency on October 26, just when the writer was in camp at the foot of the active north cone on Mauna Loa, but he felt no shocks. A similar lack of correspondence between perceptibility and seismographic evidence 35 miles away was shown in the middle of October. Local earthquakes of large amplitude were registered at Kilauea indicating Kahuku distances and were classed as moderately strong; these these were not felt at Honomalino, the ranch closest to the eruption, and four so classed October 16, 17, and 18 were not noticed at Hilea, east of the active ridge. According to the theory of epicenters, all these earthquakes should have been strongly felt. This is not the first time that such discordance between computed location and the sensation of earthquake has been noted in Hawaii.

KILAUEA DURING MAUNA LOA FLOW PERIOD

We now return to Kilauea after September 27, 1919, when Kilauea Crater had sent forth revived floods over its northern floor from the Postal Rift source cones, north and west of Halemaumau. At the beginning of October the lava column in Halemaumau subsided a little, but the gas pressure continued strong. There was recovery the second week in October, and by the middle of the month the Postal Rift flow increased its outspreading so that new upwellings and outskirt tricklings developed at the front of the flow under the north wall of Kilauea Crater, 2 miles from the source. This kind of activity continued throughout October, with the flow filling the northern part of Kilauea Crater with wide sheets of glowing lava, while the bench magma and the lava lakes in Halemaumau fluctuated.

At the opening of November 1919, when the Mauna Loa flow declined, the effusive activity of Kilauea increased. The tremendous flooding of the Postal Rift flow had indicated an adjustment between the height of the partly hardened lava column in the pit and the escaping lake magma pouring through some subterranean conduit to the Postal Rift cone. The front of the flow in the north corner of the greater crater was now sending out arms rapidly southeastward across the northeast end of Kilauea Crater and threatening the Volcano House trail.

The topography of this flow was now divided into three parts: The source region was a ridge of crusted tunnels extending from Halemaumau to the big west bluff over Kilauea; the pooling region was a field of semicrusted glowing lava filling the north end of Kilauea Crater; and the flowing region made new lobes moving eastward from this pool along the wall valley, at the base of the Volcano House bluffs. The pooling region appeared at night like a lighted town, some smoking driblet cones suggested factory chimneys, and along the base of the strata of Uwekahuna bluff the old ash locality and the gypsum-crystal locality farther north were obliterated under 10 to 20 feet of new lava.

The second week of November so increased the lava floods on the Kilauea floor as to overflow the main trail leading from the Volcano House to Halemaumau. The benches and floors of hardened lava in the pit were stationary, and the lakes sank a little, while at the same time came 10 feeble earthquakes November 11 to 13. The week ending November 21, 1919, produced such a flood of liquid lava that the source cones and tunnels of the Postal Rift were surcharged to overflowing, and even the lakes of Halemaumau rose and overflowed suddenly. This increase of outflow, immediately following the cessation of Mauna Loa, led to a comparison with the 1916 sympathy and to the query, "Has Mauna Loa not yet reached its climax, or is this the gush preceding that climax?"

The following prophetic remark is quoted from the Bulletin of the Hawaiian Volcano Observatory for the week ending November 21, 1919.

> "It is too soon, at present, however, to assert that a strong collapse at Halemaumau may not still be in preparation, the condition of Mauna Loa being somewhat doubtful, and the effervescence of Kilauea ambiguous with reference to the movements of the deeper lava column."

PIT-BOTTOM SUBSIDENCE, NOVEMBER 1919

This prophecy was most dramatically fulfilled on November 28 by the biggest collapse in Halemaumau pit ever seen by the Observatory officials. All that happened, which might be construed to forecast this event, was the ending of the Mauna Loa eruption, and a sympathetic lowering at Kilauea was expected by analogy with 1916, and there was a smart earthquake at 9:58 p.m., November 25, with origin about 110 miles from Kilauea. This earthquake was felt strongly on Maui. The Kahuku source region of the Mauna Loa eruption was smoking November 19, but no moving lava was seen by the cattlemen. Mauna Loa lava was sinking into the depths.

Until midnight November 27, 1919, Halemaumau was, as it had been for many months, a craggy dome above the level of the pit rim, with a clover-leaf arrangement of three lakes, rapid streamings, and the Postal Rift source cone a few hundred feet to the north, feeding a torrent flowing away to the north through tunnels. Far away at the base of the east wall of Kilauea, after more than 3 miles of flowing, this lava at its front was very bright, puddling and spreading.

At 1:42 a.m., November 28, earthquakes began. Seventy-five shocks were felt between 1:58 and 4 a.m. Instrumentally 200 shocks were registered. At the south pond Halemaumau became very bright; a cascade was tumbling from the main lake. The sharply outlined crag, inside the pit rim, where visitors had been climbing the evening before, flattened out and disappeared. In less than a minute the entire Halemaumau inner dome subsided out of sight. The openings of the Postal Rift tunnel became dull. Dense avalanche clouds of dust shot up. Then came continuous roaring.

The pooled flow on the outside floor (Pl. 34b) grew brighter, with ponds fountaining and spraying, as the pressure from the source was withdrawn. This continued for some hours. Release of pressure favors escape of gas in solution.

The pit was visited within an hour. The interior glow had diminished. There was the noise of sliding. The whole filling of the former pit had gone down 400 feet. The walls were vertical, the diameter was 1200 feet, big talus cones with glowing edges were visible far below, a small partly crusted lava lake was bubbling in the bottom of the funnel, and a layer of cracked glowing matter scaled off the walls in powdery avalanches of firework. Gas puffed from vents far below. The Postal Rift tunnel seen at the windows was glowing brilliantly, entirely emptied, where before had been a river of melt.

PHASE OF KILAUEA OUTFLOWS, 1919-1924

IMMEDIATE RECOVERY OF HALEMAUMAU LAVA

The next forenoon (November 28) the lava column was adjusted and preparing a spectacular rise. There was a triangular lava lake 591 feet down. Some traces of the crag topography pushed through the talus. A veneer of glowing matter was molded against the walls of the pit, vertically striated, 2 to 5 feet thick (maps, pl. 79).

THICKNESS OF BENCH MAGMA DEMONSTRATED

This was the wall-crack ring-dike which had surrounded the lava column. As it extended over 500 feet down, it proved that the depth of the semisolid lava we call "bench magma", the inner hard substance bounded by the annular dike, was at least 500 feet. Probably the lubricating action of this pasty dike permitted the sudden quiet descent of the lava column (Pl. 34d). A new puffing cone was making trickle flows in the bottom.

BIRTH OF SOUTHWEST RIFT CRACK IN HALEMAUMAU

A northeast-southwest cross crack had appeared, upright, on both walls for the lower 400 feet, with the walls coming together above. This showed as a gaping black crack, at two points just opposite each other, in both the northeast and southwest walls of Halemaumau. It was a deep vertical break through the Kilauea inner rock, and where this crack emerged at the surface of the Kilauea floor southwest of Halemaumau it was fuming, a few hundred feet outside the pit rim.

The subsidence, in other words, had been coincident with a fault movement along the line of Kau Desert cracks extended into the fill of Kilauea Crater. These southwest-trending "1868" cracks are an ancient feature of the outer flank of Kilauea Mountain. To have one of them suddenly gape open, in the bottom wall of Halemaumau portended that if the lava rose again in the pit it would outflow from the desert, as in 1823 or 1868.

The subsidence was completed in a few hours, the earthquake swarming entirely ceased after daylight of the morning of the collapse. The heaviest trembling was in the first half hour. Only five feeble earthquakes were registered after 8 a.m. The liquid lava recovered very rapidly and the next day was forming a large lake.

SPECTACULAR RISE, DECEMBER 1919

The year 1919 was crowding events one upon another, and, as the sequel proved, this was the culmination of lava pressure for this cycle (1913–1924). Beginning 1920, the lava column subsided, with outflows on the Kilauea flank, ending with the sea-level downbreak and engulfment steamblast eruption of 1924.

Thus this subsidence in Halemaumau of November 1919 appeared to be a balancing of the internal lava column to adjust some condition of lava inside Mauna Loa after the outflow on that mountain. After the adjustment was made and the Mauna Loa outlet sealed, all the gas pressure released under Kilauea took immediate effect, inducing most rapid and prolonged rising inside Halemaumau.

The first day after the subsidence a large lava lake formed; the second day springs of lava cascaded down the talus into the lake; then the ring of the old floor under the talus rose bodily and cupped toward the lake; then the gaping wall crack engulfed the talus; and by the end of a week curved ponds of boiling lava in this encircling chasm *rose to heights over 100 feet above the central lake* and cascaded inward over the ring-crags.

This was an astonishing reversal of the usual process, whereby the ring-flows bear down on the margins and push up the central floors into crags. The ring-talus of the subsidence had forced the new spurting lava to bear down on a heavy basin in the center. Four days after the subsidence, the ring-margin, consisting of the old floor, was lifted 33 feet in excess of the rise of the central lake. But the central lake had also risen, averaging 36 feet per day. Still more remarkable, the liquid lava in the peripheral ponds, outside the ring-crags, had been rising 50 feet a day. The whole lava column rose 200 feet in 4 days.

TALUS CEMENTED AND LIFTED CLEAR OF FUNNEL WALL

The entire lava column that had gone down, including the bench magma below and the lake on top, was now rising with unheard-of rapidity, and the lava percolated through the talus. The rising of the bench magma around the edges simply lifted the semented talus ring clear of the wall of the pit and revealed bubbling pools of lava welling up in the wall crack back of the talus. These bubbled up above the quiet lake in the center and sent cascading flows down into that lake.

In 14 days the central lake rose 444 feet, and the highest part of the ring-crag rose 486 feet. This crag mass was a single great crescent, like a coral atoll (Pl. 33), surrounding a quiet lagoon and surrounded by a violently effervescing ring-lake. This ring-lake showed traveling fountains and produced intense glow and heat. Rising was 30 to 40 feet per day.

COOLING OF POSTAL RIFT FLOW TUNNELS

In early December 1919 the Postal Rift tunnel gradually cooled off from upstream downward, the upper collapsed tunnels becoming black sooner than those farther down the slope. These could be seen into through certain windows where the roof had caved in, and the downstream windows still showed bright orange glow inside. So it was also with the flows at the front; at first active, they gradually dwindled, and the flow area cooled off. The tunnels were hot for months.

BIRTH OF "RED SOLFATARA"

The new smoking crack extending southwest on the Kilauea floor from the edge of Halemaumau developed a line of dense blue sulphurous smoke mixed with steam from the ground about 300 feet from the pit. This was the trace on the surface of the vertical fracture in the lower pit walls, which had cracked across the wall veneer. If this veneer solidified after the early morning of November 28, then this crack opened still later.

The inexplicable feature of this crack was that it widened downward. It was tight together upward but was a smoking fissure at the surface, outside of Halemaumau southwest. In its wide open portion in the lower pit walls, the rising liquid pond lava was pouring into it and filling it, under the place where it was smoking outside. It was this gassy lava fill below that was making it smoke above, and the acids of sulphur were decomposing fresh lava where the crack emerged.

By December 13 the ring-crag peak in Halemaumau was above the edge of the pit, in full view of the distant Observatory, and rising steadily more than a foot per hour. The measurements were made with a micrometer scale, in a telescope, at the Observatory.

The multiple fountaining of the ring pool roared like a cataract. There were strong streamings and whirlpools. The scene was magnificent, even compared with the great fountains of 1912 and with the Mauna Loa displays. Spatter lumps of dense black glass were hurled above the rim.

The grand crisis that inaugurated flank outflow from Kilauea came December 15, 1919, but it began inside Kilauea Crater. The whole "atoll crag" was visible from the Observatory. The fountains boiled tumultuously only 20 feet below parts of the pit rim. The opening in the crescent crag, where the inner quiet lagoon communicated with the violent outer ring-lake, was toward the west. In this lagoon occasionally enormous dome fountains broke the surface crust. The heat at the actual rim of Halemaumau was insufferable. The southwest smoking crack, hereafter called the Red Solfatara, an interesting feature for years, was swelling and groaning (Jaggar, 1921). Fragments were falling into the crevasses. These chasms were red hot inside from gas action. At 11 a.m., December 15, a puddle of lava had welled out of this crack near the smoke holes, 600 feet from the Halemaumau edge.

CRISIS OF DECEMBER 15, 1919, THAT SPLIT OPEN KILAUEA MOUNTAIN

At 11:25 a.m. a puff of dust and fume shot up near the southwest edge of Kilauea crater. The mountain was opening under the enormous lava tension. Instantly and quietly, the ground opened radially from Halemaumau across the Kilauea floor (Pl. 34e), along the line of the Red Solfatara southwest. Two hundred small fountains of very liquid lava burst up. The melt bubbled and spread right and left. The length of the bubbling was 0.4 mile. This crack united with the Kau Desert cracks, outside of Kilauea, and the latter began to show motion and avalanching on the outer Kilauea cliff. The new flow became a mile wide in the Kilauea wall valley. Near the pit, down the fissures, molten lava could be seen flowing 15 feet beneath the surface, showing that this flow was draining Halemaumau.

Within an hour the Halemaumau lake had drained down to the outflow level, and the external flow stopped. The Halemaumau lake went much lower, and the flow on the Kilauea floor became a sheet of collapsed shells.

START OF KAU DESERT FLOW, 1919–1920

On December 15, 1919, outside Kilauea Crater, in the Kau Desert southwest, the old fissures opened (Pl. 37) and started steaming, something unheard of for many years past. A zone a quarter of a mile wide showed fresh breaks in the gravel. The new cracks extended 1½ miles from the Kilauea edge. Creaking and tumbling were audible in the cracks, one was 80 feet deep and 5 feet wide, and acid sulphurous vapor arose of temperature above 100° F. The smaller fractures were of all sizes, and there were five conspicuous steaming places.

The lava in Halemaumau recovered, and there was again outflow through the same southwest cracks of the Kilauea floor, building up a large slag heap there until December 23. The inner crag again came into sight from the Observatory, and on December 22 its top was level with the rim, while the fountains in the pit reached a maximum of fury. The heat started whirlwinds, carrying up fragments of lava.

Beginning December 23 the lake started lowering, the crags going with it with some lagging. From a depression of 40 feet on that day, the lava lake of Halemaumau reached on January 1, 1920, a depression of 255 feet. When at the highest, December 23, the outer ring pools had measured about 1400 feet north-south by 1200 feet east-west—the dimensions of the pit mouth. On January 1 at the lower level the diameter of the lake east-west was 1115 feet, showing how steep was the containing cylinder.

KAU DESERT FLOW, 1920, SOUTHWEST FLANK OF KILAUEA MOUNTAIN

From 1920 to 1924 the lava escape was confined to Kilauea and was declining, with spurts of rising in the pit and spurts of overflow and outflow, always on Kilauea Mountain, and about Halemaumau as a center. The outflow in the Kau Desert, throughout the first half of 1920, pulled down the lava in the pit apportionately, and the latter part of 1920 there was intense revival of the pit lava.

The rending open of the rift system southwest from Kilauea recalls the events of 1823 (Stearns, 1926; Stone, 1926a) and 1868 (Wood, 1914b; Stearns, 1930; Wood confuses with 1823 flow). In both years the Kilauea lava lakes were very large and lowered greatly during the outflows in the Kau Desert, which in 1823 (Pl. 42) made a big flow to the ocean originating 15 miles southwest of Kilauea, and in 1868 made a small puddled area only 10 miles down the desert.

At Christmas 1919 the Kau Desert broke open along a single pair of fissures of the rift belt, extending through the small cones that lie a mile southwest of Kilauea Crater; the two cracks were a quarter of a mile apart; the upwelling of lava located itself at three places, respectively 4, 6, and 9 miles from Halemaumau.

On December 21, 1919, the 5-foot chasm of December 15 was 15 feet wide (Pl. 37), just outside of Kilauea Crater to the southwest; near by was a crack 4 feet wide, and in it, 50 feet down, sluggish pahoehoe threw out incandescent toes and caused heating and snapping of the adjacent rock.

FOUR-MILE OUTFLOWS

About 4 miles down the mountain the same day (Pl. 35a, b), the lava rose to the surface level, filling the two cracks with heavy black pahoehoe hissing gas vents built up small spires or made roundish, heaving puddles. In some places, the west crack was overflowed in puddles 30 to 50 feet in diameter; the east crack was a quarter of a mile away and parallel. About half a mile west of Puu Koae the western crack gave up bluish-brown fume, strong with sulphurous acid; all along the line for half a mile in this chasm, 2 to 4 feet wide, black lava built spires, spiracles, and heaving puddling vents; the activity appeared to have slowed down from a day or two before. Farther down the mountain both cracks were invisibly extending themselves.

SIX-MILE OUTFLOWS

In the early morning of December 24, the 4-mile locality had slightly increased its outflow, the cracks had extended themselves down the mountain, and a flow in the desert about 6 to 8 miles from Kilauea was seen. This consisted of three sheets of pahoehoe lava moving steadily and slowly along the top of the rift, with rift fountains playing in a line down the middle. It was a dike which reached the surface. The flowing area was about 1½ miles long and an eighth of a mile wide at the widest part, this wide area at the lower end being essentially a flat-top slag heap, with slow streaming down the middle toward the rift. The border flows invaded trees and bushes to the west, these flared up, and there were detonations of exploding gas in old caverns. The formation of a slag heap was a replica of just what was building at this time on the south floor of Kilauea Crater.

NINE-MILE OUTFLOWS AT SAND DUNES

Farther down the mountain along the fissure, the ground was groaning and heaving, making small earthquakes and yielding sulphurous vapor from many cracks. In timbered country where there were large sand dunes 80 feet high, the live crack in the rock beneath trenched these dunes (Pl. 35d), pebbles and sand fell in the crevices, and incandescent lava 40 feet down welled up slowly and made crackling noises.

The flow was progressing by a splitting of the rift downhill and a subterranean draining of Halemaumau, each upwelling more voluminous than the preceding, and the individual outflows decreasing in viscosity. On December 25 the sand-dune locality, 9 miles from Kilauea, was making a new flow that was burning the forest (Pl. 35c). Several driblet cones had formed, feeding a wide, flat flow surface 4 or 5 feet high, with fountaining over the rift line, slow streaming South–Southwest, and mobile pahoe-hoe sheets 1 or 2 feet thick spreading into the forest.

There was strong odor of coal gas and burnt organic matter, and the numerous explosions in old cavernous spaces were clearly occasioned by a mixture of such gas with air. This gas is due to burnt vegetation. Where a fresh lava flow penetrates old caverns in a nonvegetated country, as on upper Mauna Loa, no explosions occur. The live crack downhill from this flow extended for only 100 yards, yielded some white vapor, and showed no perceptible motion. The longest lobe of the flow was half a mile long and had a maximum width of an eighth of a mile.

ELEVATION OF THE OUTFLOWS

The lake in Halemaumau was at an elevation of about 3450 feet, the 4-mile locality of outflow was at an elevation of 3250, the 6-mile locality that piled up was at an elevation of 2900, and the 9-mile heap arose at an elevation of 2650 feet. Thus the lowering Halemaumau column was about 500 feet above its drainage vents.

On December 26 the 9-mile lava heap was piling up, but the 6-mile heap in the open country was gaining on it in activity, and the rift under this heap as extended downhill was a quarter of a mile west of the rift under the 9-mile sand-dune locality. These cracks were only 1–2 feet wide when gushing, buried themselves quickly under accumulations, and narrowed to mere rock joints in their downhill extensions.

FIRST AA FLOW

During the week ending January 2, 1920, the 6-mile slag heap gave vent to a long vigorous aa flow (Pl. 36e, f). The heap started to produce small aa patches on its flank December 29, and on the morning of December 30 it ejected the big flow. This flood traveled about 2 miles per day. It was pahoehoe at the source that quickly changed downhill to aa and formed a straight river of lava which bent off to the south-southwest and swept through the depression immediately west of Kamakaia cones. It progressed about 5 miles and was nearly stationary by January 3.

Halemaumau showed subsidence of its lava at a decreasing rate, the drainage of the lake magma becoming strikingly less when the outflows in the desert changed from pahoehoe to aa.

The 9-mile slag heap had built up until it was 60 feet high (Pl. 35e), with three or more fountains playing on top in a stagnant pool. From the top of this the new aa flow could be seen off to the east as a glowing river of melt extending up the country about 2 miles, taking its origin in the upper part of the long terraced ridge of new lava at the 6-mile locality. It proved to be a band of lava 100 yards wide, its margin a wall of rough incandescent sprouts and boulders 5 feet high, its middle portion creeping along 4 feet per minute. The crumbling fragments made a tinkle of hard chips, intensely oxidized even when incandescent. Slabs of pahoehoe were scattered over the surface of the flow, and toward its source the river became increasingly ropy, until at the upper half mile of the flow the surface material congealed in the smooth and festooned skins of true pahoehoe with no clinkers.

DISTINCTION BETWEEN FLOWING PAHOEHOE AND AA

A word of explanation is necessary in speaking of live lava as Flowing Pahoehoe or Flowing Aa (Pl. 39). The words "pahoehoe" and "aa" are commonly used of already solidified products. The difference between the two types when in motion is this:

Pahoehoe Lava (Pl. 73) forms glistening skins which stretch and wrinkle (Pl. 35f); the lava beneath shows vesicles being drawn out, and the process of solidification leaves a highly glassy lustrous surface with rounded, ropy, or serpentlike forms. As flowing lava is always congealing on the surface and at the sides, the nature of the congelation defines the nature of the flowing.

Aa Lava while in motion forms no skins and is characterized by a granular (Pl. 71a) look and resembles a bed of hot anthracite coal flowing. This granular paste keeps rolling up lumpy balls (Pl. 71b) of its bottom material, and these make slow-moving rafts and islands. Around the edges or front of such a flow, the glowing paste moves with an incessant cheesy crusting and breaking. The part actually glowing is usually a thin layer, which rides over tumbled fragments of very rough shapes and carries on its back highly scoriaceous, rusty, and dull fragments.

There is no bubbling or visible vesicularity to an aa front, though the cold rock contains irregular gas blebs. When there is a transition from pahoehoe to aa in the process of flowing, the stirring and crystallization factors exert some control, the wrinkling skins and crusts of the pahoehoe pass down the middle of the flow, and the edges start sprouting or arborescing (Pl. 73d) in the clinkery aa fashion (Emerson, 1926).

SOURCE OF THE MIXED FLOW

The source of this aa flow was an amphitheater in the flank of the hard plateau slag heap (Pl. 38) at the 6-mile locality. The lava river poured across the bottom of the amphitheater swiftly and silently with ripples and rapids, 100 feet wide in places, flush with a bank of its own overflooding, and this sloped away on either side so as to leave the stream raised about 12 feet above the general level of the country. All this was smooth pahoehoe. The whole accumulation, banks and river, thus created below the source hill a lower ridge 100 yards wide, with the river advancing along its middle.

The source of the stream was a pit 10 feet in diameter, with a driblet rim, up which the lava welled continuously in a fountain about 3 feet high. This torrent bent at once into a cascade feeding the river below. The surface of the lava so emerging was full of coarse, drawn-out vesicles. It made no noise and showed no gas spurting. In the upper part of the river there were a few small bubble fountains.

It would be hard to imagine a greater contrast than between this utterly quiet Kilauea sewer pipe venting its liquid and the tremendous froth pools and froth fountains of Mauna Loa 2 months before. Both produced pahoehoe that turned into aa half a mile from the source.

SECOND AA FLOW

On January 2, 1920, the 9-mile lava heap in the sand dunes was 80 feet high and exhibited no more fountaining on top. Two days later the western side of this heap was breached, a sink had formed in its summit plateau, and from the breach a sluggish mass of aa, carrying huge tumbled crags of the original pahoehoe surface matter, had proceeded a few hundred feet, more like a landslide than a river.

DWINDLING OF THE FIRST FLOW

By January 9 the 6-mile lava heap was 50 feet high, and the stream pouring south had dwindled to a width of 40 feet. The flow was 8 miles long, and the front was advancing about half a mile per day.

The Halemaumau lava had continued to subside, but the rate of subsidence was reduced from 20 feet to 6 feet per day.

The appearance of the bottom of Halemaumau at this time (Pl. 34f), with lakes 300 feet down and crag summit 55 feet above the lagoon, was very spectacular, owing to excessive multiple fountaining in the marginal ponds. These were separated from a central lagoon by the horseshoe ridge, and the lagoon was a quiet liquid with soft skins and a few fountains. At the west this lagoon connected with the outer ring of pools.

The flow in the desert widened a large pool of aa by about three quarters of a mile in the region west of Kamakaia. The extreme front lay 2 miles south-southeast of "Puu Kouele" (or Puu Kou).

The surface of the 6-mile slag heap had subsided in a sink, just as had happened at the 9-mile locality.

HALEMAUMAU IN ADJUSTMENT WITH OUTFLOW

By the middle of January the subsidence of Halemaumau lava ceased, with the lakes 337 feet down; the desert lava flow continued to pour out quietly, shifting its course, covering new ground near the source, both east and west of the aa river, so that the advance on the front of the latter ceased. The front of this long flow stopped about 6 miles from the sea coast. Except for short aa flows as breakdowns of the slag heap, the rest of the flowing for months to come was destined to be a progress of pahoehoe streams from the middle or 6-mile slag heap, largely on the east side of the former aa flow, each stream crusting over and thereafter progressing by tunnel flow. This tunnel flowing of pahoehoe reached almost as far down the mountain, through the months, as the aa flow had done in a few weeks.

GENESIS OF MAUNA IKI

The third week of January produced slight rising in Halemaumau, and the Kau Desert flows built up the 6-mile source (Pl. 36) mound of slaggy lava. This mound, hereafter designated as Mauna Iki, from its resemblance to a baby Mauna Loa, was now 2 miles long in the alignment of the rift and 100 feet high, with three crusted pools (Pl. 41c) on top. The first pool was surmounted by a standing fountain in an oven cone. The others were fountaining spasmodically, and flows of slaggy lava were building up the heap, especially toward the west.

FEBRUARY 1920 AT HALEMAUMAU AND THE OUTFLOWS

Rising began to appear in Halemaumau, and this involved development of arms of the central lake, through cross fissures in the ring of crags. Three such arms developed just where the three lakes had been in 1919, respectively north, southeast, and southwest. This repetition seemed to mark some kind of deep fracturing in the bench magma, with swelling and uplift in three sectors. Rising was higher in the main lake than in the marginal ponds, restoring cascading from the center outward in contrast to the cascading from the periphery inward noted early in December. The basin warping of the central bench magma had changed to a dome warping, and the pit floor material at the north rose so as to produce a southward tipping of the ring ridge.

Early in February new small flows overran the north edge of the Mauna Iki heap, and on February 1 a breakdown on the east side of the heap produced a craggy and rugged short aa flow, draining the stagnant fill of pasty lava which had been formed in the core of the heap under the recently quieted middle pool. An amphitheater opened into a narrows, where pahoehoe slabs were turned up as crags, and below that a fan of aa flow. In mid-February rising at Halemaumau continued, and Mauna Iki again reached a climax of heaping and developed an eastern depression and a short aa flow.

The third week of February produced increased rise in Halemaumau, with uptilt of the ring of crag blocks away from the center, crowding out of the wall ponds, and centrifugally inclined shore-line terraces lifted about the central lake.

The flow heap at Mauna Iki continued to build up as pahoehoe and break down as aa, in alternations (Pl. 39), as though there were a critical height of about 125 feet for the heap. Beyond this the pressure appeared to breach the flanks, and the accumulated paste inside flowed as sluggish aa.

COMPARISONS BETWEEN HALEMAUMAU AND MAUNA IKI ALTERNATIONS

This alternation suggests interesting comparisons with the Halmaumau alternation of rising lake and lifting shores. In Halemaumau the rise of the lake and the accumulation of bench magma beneath occasioned an outward pressure of the paste which lifted the crusted marginal material. This may be analogous to the outward pressure that breaches the Mauna Iki heap.

AMPHITHEATRAL BREACHING IN HAWAII

Another comparison is between the oval amphitheaters at the head of each breach in the slag heap and the open oval sink craters common in Hawaii on a much grander scale. Such craters are Mohokea (Hitchcock, 1906; Stearns, 1930) and Wood Valley in Kau. Haleakala Crater is somewhat similar, and the craters of Kilauea and Mokuaweoweo are sinks similar to the sinks on the top of Mauna Iki, that in some cases breached the flank and made amphitheaters. Kilauea Crater is a crescent open to the south.

The glow of Halemaumau and the lava flows were seen from a vessel 190 miles east-southeast of Hawaii at 10 p.m., February 16.

Rising continued at the end of February, and flowing from the Hawaiian volcanoes had now been continuous for a year, first over the Kilauea floor, second from Mauna Loa, and third from the Kilauea flank at Mauna Iki. The rising in Halemaumau slackened, and the craggy matter developed at the expense of the lake.

The Kau Desert heap poured floods of pahoehoe in torrents down the slopes of its self-made eminence, in directions squarely contrary to the general slope of the country, building extensions up the rift and widening the skirts of the ridge of accumulation.

INTERNAL TUMEFACTION IN HALEMAUMAU OBLITERATES THE RING POOLS

The first week of March clearly showed that the bench magma under the lava lakes had broken in three sectors exactly like a saucer fractured from the center outward in three straight cracks, so as to let the gas and liquid come up the cracks. The fountains in the lakes were in lines along the three radial arms over these cracks. Moreover, the tip of each sector was lifted so as to make a visible shoal in the lake. The three crags nearer the walls of the pit had been lifted, as though the edge of each saucer arc were raised and tilted a little on an outer corner as a pivot.

The tumescence in the center converted the shoals into three islands. The general swelling apart of the triangular fragments let the liquid into the cracks nearly to the saucer's rim and so developed three fountaining arms of the pool beyond its circular central area, like three spokes of a wheel. Continual uplift of the sector blocks converted the three islands into peninsulas.

This process had transferred all the fountaining to the central lake, and the ring pools were extinguished by the wedging of the remains of the ring crag (the saucer's edge) against the funneling walls of the pit. The only traces of these marginal pools were blowing cones in the wall cracks.

The Kau Desert heap continued to build with a lava cascade pouring down the upper slope into a tunnel and both aa and pahoehoe spreading out to the north and east.

HALEMAUMAU BUILDS IMPRESSIVE CRAGS

At the middle of March the lava lake was 217 feet below the Halemaumau rim, and the islands and crags had become impressive features, eight separate peaks standing 30 to 110 feet above the liquid lava. The highest, the north crag, was only 94 feet below the pit rim. The three main fiery arms of the lava pool, shaped like a Y with the stem pointed toward the Kau Desert flows, had currents streaming toward this stem, and the stem ended at the vertical crack in the wall which resembled an arcade, leading through the mountain to the distant outflows.

The desert flows were never more brilliant, and a torrent 20 feet wide poured into a pit on top of the lava ridge, and then out from a round well down the outer slope. The stream cascaded over terraces below.

Rising continued to the end of March in Halemaumau, the crags tilted, and the lake arms tended to become ponds. The lava heap in the desert continued to send out flows from several sides, making much of the heavy sharkskin type of lava.

APRIL 1920 FINDS BOTH HALEMAUMAU AND MAUNA IKI IN ACTION

At the beginning of April (Pl. 40b) the lava became stationary in the pit, and fume increased. There was streaming of cascades and rapids into holes. At Mauna Iki in the desert a terrace was being built up around the north and northeast sides of the main slag heap, and lava was pouring through tunnels in all directions and spreading out around the foot of the heap.

The lava in Halemaumau continued to rise, enlarging the lake and encroaching on the crags. The northeast terrace of Mauna Iki broke down and became the source of a considerable flow to the east. This flow increased throughout April, the torrent pouring eastward and southward through tunnels. After April 16 the liquid lava of Halemaumau lowered in sympathy with increased outflow in the Kau Desert.

HALEMAUMAU AND KAU DESERT CONTINUE JOINT ACTION

The lava column of Halemaumau started to rise again on May 6; the lava lakes were 156 feet below the rim.

A cone 40 feet high had formed on top of the main lava ridge of Mauna Iki in the desert, and the persistent river of pahoehoe continued to flow in tunnels (Pl. 41) off to the east and south.

There was a return of lowering, with a lava cascade on one arm of the Halemaumau lake on May 11, and the Kau Desert flow continued to spread to the south and east. The summit cone on Mauna Iki simulated a miniature volcano by producing small explosions after a period of quiet. The third week of May marked the end of the fifth month since the Kau Desert flow began, and much lava was still pouring out. The active part of the pahoehoe flow, east of the former aa flow, extended for more than 3 miles from the northern part of Mauna Iki to a point below Kamakaia (map, Pl. 85).

At the end of May the lava column of Halemaumau (Pl. 43a) continued to fall, and the arms of the lake separated into four distinct lakes. Avalanches fell from the crags. The lake level was 185 feet below the rim on May 28, 1920.

Mauna Iki in the desert had settled down to steady flowing through the tunnel, and no noticeable change in volume output, in the Kau Desert, accompanied the subsidence in Halemaumau.

Rising was resumed at the pit in June, and the fume there immediately decreased. The maximum upwelling appeared to come from the west side of Halemaumau bottom, with streaming out of the western arm.

At Mauna Iki there were rumbling and cracking noises, and the pahoehoe flow continued to advance far to the south, but the region around the source hill, except for the hot ground and occasional windows in the roof of the lava tube, would not have indicated, to a stranger, a place of outwelling lava. At the windows, the lava was lowering in its tube (Pl. 41), for, where it had been near the surface a month before, it was now 20 feet down.

Halemaumau stagnated in the middle of June; at Mauna Iki in the desert a fountaining lava lake was revealed by a breakdown near the north end of the hill. This lake at the end of June alternately crusted over and fountained explosively. The main flow from Mauna Iki was pushing forward as sharkskin lava, away down the mountain below Kamakaia, where it invaded the forest and made tree molds.

At the beginning of July Halemaumau was a large circular caldron, occupied by lava lakes and crags, which made much smoke. There were two inner shelves on the north side of the pit. There was increased subsidence of the lava, making debris fall from the crags and walls, there was a somewhat regular central fountain, and streaming was outward from the southwest pond. Great masses of Pele's Hair accumulated in mossy banks on the northeast wall of the pit.

The Kau Desert flow had now progressed about 5 miles from Mauna Iki, moving parallel with and east of the January aa flow and banked up against it. The whole tract of country, a quarter to half a mile wide, between the January flow and the Kamakaia hills was flooded with a new pahoehoe, and the advancing front was a mile or so south of these hills.

HALEMAUMAU LAVA RISES, AND KAU DESERT FLOW CEASES

Lowering in Halemaumau stopped August 1 at 320 feet below the rim. Then came a rapid rise, the crags faster than the lakes. The Kau Desert flow was increasing its smoke and decreasing its activity. The rising in Halemaumau slightly revived the Mauna Iki center, but after the middle of August Halemaumau was being flooded with liquid lava, as though the fluid were backing up from the stoppage of the desert flow. That flow had continued for 8 months, and, while Mauna Iki and its tunnels remained hot for years, this was practically the end of the phase of southwestern active flowing from the Kilauea flank.

Halemaumau showed slight lowering at the beginning of September 1920, and the tunnels of the Mauna Iki flow were increasingly caving in. At the Red Solfatara on Kilauea floor, just outside Halemaumau to the southwest, dense masses of acid fume were rising from the vacated tunnel below (the tunnel leading to the Kau Desert flow); and the Kilauea floor there was decomposing, with development of brilliantly colored solfataric patches (selenium, sulphur, sulphates).

The liquid lava in the pit sank a little, cracking the bench magma and producing cascades, so that in mid-September a flood of molten stuff rushed over a ledge into a swirling caldron of glowing lava at the southeast pool. An irregular circular block of crags, near the center of the pit, broke away from the marginal portions and subsided with the lakes (Pl. 40a).

AUTUMNAL RISE OF HALEMAUMAU, 1920

An equinoxial rising followed, with the liquid lava up 30 feet in 2 days. The cascading ceased, flaming cracks developed marginal to the lakes, and glowing cones formed which resembled beds of hot embers. The rising was communicated to the bench magma with marked centrifugal tilt. The shores of the three-armed lake thus seemed to lower from the center outward, in the central region shore lines became crag ridges, and the marginal ponds overflowed on the side away from the center. An island collapsed and disappeared.

ALTERNATE RISINGS OF LAKES AND CRAGS

All this in October 1920 recalled the events of the autumn of 1916, when in Halemaumau there was similar alternation between liquid flooding and lift of the crag sectors. The fountains were now increasing in number, spatter ramparts began to appear, and overflows were filling the down-tilted margin along the wall cracks. Such tumefaction is really uptilt at the lake center. In the second week, the crags rose faster than the lakes, and, where the Kau Desert arcade emerges, inside the pit, a 10-foot cone developed, giving vent to liquid lava. The Red Solfatara outside, over this arcade on the Kilauea floor, was making increasingly dense fume, though the vapor in the pit was thin.

Pronounced swarms of small local earthquakes were registered instrumentally the third week of October, and flooding of liquid lava replaced the rising of the bench magma in accordance with the usual alternation. This reached a climax on October 23, when the whole bottom area of the pit was flooded and the crag hills were isolated.

There was a smart earthquake on October 27, followed by renewed rising at Halemaumau.

CONVECTIONAL LAVA CIRCULATION

During all these months the lava lake fluctuated about 200 feet below the rim of Halemaumau, and that was the depression at the beginning of November. There was a sinking with cascades and small avalanches, and the largest lake was an octopus affair, its tentacles forming a fiery stream, which ended in a cascade forking about a ledge, and falling in brilliant rapids to a lower pool, where the glowing melt surged and swirled with scintillating golden pattern. The pool where the stream arose, on the southwest side, was at least 15 feet higher than the southeast sinkhole pool, where it ended in a fall. All this flowing is part of the convectional circulation whereby the hotter and more foamy lava rises at the west and the cooled and heavier substance sinks away at the east. The underground tubes, which convey this effervescing fluid, ramify through the paste which forms the crags and floors, and the paste extends indefinitely downward.

GAS HEATING WITHIN CRAGS

That these crags were red hot was shown by the west peak, which until November 12, had a summit chimney consisting of a mass of cracks glowing and flaming and in daylight ejecting puffs of dense white fume.

The mechanism whereby such crag peaks become undermined by gas fluxing was illustrated on November 12 when this summit collapsed and left a pit, where bubbling lava was welling up amid the fallen debris. Lava subsiding in a cup below had produced collapse by undermining, and the dense smoke disappeared when the condensing chamber was destroyed.

By this time the open cracks of the Red Solfatara outside Halemaumau, also emitting dense clouds of poisonous acid vapor, had recently become red hot close to the surface, where early in September the temperature had been less than 200° C. The new temperature was at least 800° C; the heating was entirely attributable to rising gases, for no lava was visible in the cracks, and the connecting lava of the pit, in the arcade far below, on this southwest rift of Kilauea Mountain, was 233 feet down.

PLATFORM BUILDING AT EXPENSE OF LAVA LAKE

After November 15 the pit rose a foot or more per day, which augmented in strong pulsations about November 23, so that the central lake built a fresh inner platform. This increased in area so as to retain five small ponds, the only remnants of the eastern part of the lake. Former islands were buried under the new platform, and a small central fountain became a cone on the platform with lava streaming from it.

GREAT FLOODING OF LIQUID LAVA

The rising of 5 feet per day in Halemaumau became a tremendous flood from all the lakes, which rose twice as fast as the crags. The separate lakes lost their identity.

On December 2, a standing fountain of the artesian type was a central source for an eastward flow in Halemaumau. A new symmetry had developed, with the four outer pools at the corners of a square, the central lake in the middle, and on the intermediate diagonals, between the outer pools, four pots which had formed in crag fissures.

The rising continued throughout December so that at the end of the month the liquid lava was up to the rim level of Halemaumau, with only one important crag peak left, and boiling lava ready to overflow within a spatter cone at the Red Solfatara outside Halemaumau. In other words, December 1920 reproduced the events of December 1919, but the renovation of high-lava pressure in the pit did not repeat outflow in the Kau Desert.

On December 9 the lava lakes were 148 feet below the monument on the rim of Halemaumau, on December 18, 99 feet (Pl. 43b), and on December 29, 32 feet. The main crag peak lay 97 feet below the rim of the pit on December 9, 47 feet on December 18, and on December 29 it stood 44 feet above the rim of the pit. Such is the rising when Kilauea makes one of its spurts.

The rising proceeded as before, by alternation between uplift of bench magma and flooding of liquid lava, but the liquid dominated. In the middle of December the slaggy streams of glowing stuff were overflowing the lips of the several pools, flooding the floors, and cascading into the lowest wells. The fountains increased in size, numbers, and brilliancy. From the west bluff of the outer Kilauea Crater the splashing lakes and jagged peaks inside the pit became plainly visible. A small pond at the east, 20 feet in diameter, enlarged to a lake 200 feet long and all inside the lava pit.

NEW OUTFLOWS FROM RED SOLFATARA

By December 24 the 1919 rift crack leading to the southwest, about 500 feet outside of Halemaumau, produced a blowing vent of glowing lava and burning gas, roaring and sending up jets of flame over a veritable furnace of boiling lava. The stage was set here for a flow on the Kilauea floor. About 6 p.m., December 27, a new cone along this crack started rocket spurts of molten lava 25 feet high, from a vent 200 feet nearer the pit than the first cone, and then streams gushed out from both cones and progressed about 300 feet southwest across the Kilauea floor. This flowing continued into the new year.

From the bluffs around Kilauea Crater the scene at the fire pit became marvelous at night, the lakes gleaming with lines of splashing fountains, the southwestern flow making a fiery trail out on the Kilauea floor, the blowing cones shooting sprays of lava like rockets 40 or 50 feet into the air, and over all the great crag silhouetted against a luminous mist of volcanic fume. The pounding was heard, and the bright light on the cloud was seen, many miles away. Red Solfatara at the rift crack ceased smoking when the outflow began.

CLIMAX OF CRATERAL FLOWS, 1921

The year 1921 was chiefly famous at Kilauea (Pl. 84b, map of Kilauea) for the great fountaining and flooding of February,a nd especially of the middle of March.

These were pulsations of enormous gas pressure culminating in March, with fountaining and overflowing of Halemaumau, followed by subsidence in April. Autumn recovery was followed by another lowering.

SCENE AT OPENING OF 1921

The beginning of the year found the flow inside Kilauea Crater spreading along the sag between the Halemaumau dome and the southwest wall of Kilauea, and the liquid lava in the pit held itself level with the pit rim, approximately 3700 feet above sea level. The great crag peak within Halemaumau stood 90 feet above the liquid lava (Pl. 43c). The pit had become merely a shallow pan in the broad inner cone of the greater crater floor. Within a ring of low cliffs five boiling lakes of fiery lava were surrounded by a circular flat of fresh silvery flows, channels connected some of the lakes, and the burning gas bubbled out at hundreds of fountains amid rushing currents.

GAS IN SOLUTION DEMONSTRATED

A remarkable feature showing gas concentration in the lava was the visible swelling of blisters on the surface of the individual sloppings-over of glassy magma on the lake shores. A fountain against the bank would fling out a blob of red-hot glass; blisters several inches in diameter would swell up on the freezing paste before it completely hardened. Fragments of the shell, of such pitchstone blisters, show other smaller blisters on the inner concave surfaces. This means that gas was developing, even in the skin of a blister, up to the instant of solidification.

SHALLOWNESS OF LAVA LAKES PROVED AGAIN

The shallowness of the lava lakes was demonstrated January 28, 1921, when a fault block from a cliff of the east crag mass slipped down into the southeast channel in the pit and blocked it. The block was 30 feet above the liquid before breaking off; after sliding to the bottom it was 5 feet above the liquid. Its lower edge had been entirely above the lake. The liquid in Halemaumau was thus proved 25 feet deep. Unlike the foundering crusts on the vesicular liquid, such blocks do not founder in the denser lake-bottom magma.

KILAUEA FLOOR FLOODED AGAIN

After the middle of January there had been moderate subsidence of the liquid lava, greatly enhancing the relief of the crags, but February inaugurated new rising. All the intense activity was restored so that by the second week the fire pit produced its utmost of splendor and accessibility, and the rift southwest renewed eruption and flooded once more the southwestern part of Kilauea Crater. An island in the southwest lake rose gradually from a crusted eddy amid the currents, developed a plateau surface, and then tilted. At the north a spire 9 feet high was built in fantastic shape by gas sputtering until it resembled a peacock.

This eruptive episode passed, and the outflow at the rift gradually blocked itself by the backing up of accumulations. The lakes held levels 5 or 6 feet below their banks and from 10 to 30 feet below the Halemaumau rim. Multiple fountaining had developed a "bubble and spurt" quality, whereby each individual burst would fling up a slaggy rope, the currents carrying the fountains with them. A visitor compared them to flocks of fiery swans. Instead of rising and falling the lava level became more or less fixed, compensated by outflow. The last week in February produced gradual subsidence, the flow on Kilauea floor stopped on February 21, and again the lakes lowered more than the crags. At the rift cones of the flow source at Red Solfatara, the tunnel opening, where the lava was flowing, became dark, and the main cupola revealed "grapevine" stalactites and a glowing chamber where the lava rumbled below. Patches of white, pink, and yellow sulphates with selenium, several inches deep, were deposited by the increasing fumes, so as to decompose the fresh flows with remarkable rapidity. SO_2 and SO_3 were the corrosive agents.

FORECAST BASED ON GROUND TILT

A forecast written February 28 called attention to the fact that tilt in the seismograph cellar had "changed from southwest to strong northeast, as though rising might be resumed about the middle of March." This prediction was correct, based on an earlier investigation, indicating that east tilt precedes rising of lava by 18 days (Jaggar, 1920, p. 243).

EXPERIMENTS WITH GAS AND TEMPERATURE

Experiments in the blowing cones and liquid lava were made with pipes and cylinders to determine how gas will flow through artificial apparatus from the cupolas, the viscosity of the lava, and the temperatures at such a time of multiple fountaining. Everything indicated the correctness of the doctrine, "more gas, more heat." Temperatures were read of 1200°, 1100°, and 1190° C. The temperature was higher, and the viscosity (Jaggar, 1917C; 1920; Palmer, 1927) lower in the bubbling lakes than in the quieter lava of the flow-source cone.

RECESSION AT BEGINNING OF MARCH 1921

At the beginning of March the walls around the several lakes were sheer precipices 70 feet high in places, and the great inner crags, like steeples and castles, towered above the five lava lakes. The rift cone at the Red Solfatara maintained an incandescent interior. The activity became remarkably sluggish. Dense masses of fume boiled up at a western crag (Pl. 44a).

GREAT MARCH CRISIS OF EQUINOX

The third week produced the most spectacular rise and the most concentrated fountaining of the 11-year cycle between 1913 and 1924. For the first time in recorded history, the revival of the southern flows on the Kilauea floor (Pl. 45c) sent a tongue of overflow through a gap in the southern rim of Kilauea Crater. The larger crater thus became an overflowing crater, though the flow out into the desert was small and short-lived. Inside Kilauea sink, however, the flooding was enormous. The eruption was just at the equinox.

The week began with dull, crusted, stationary lakes. Some rising had been inaugurated March 15 when a small islet was lifted suddenly into an elephantine hill, resembling an antediluvian monster (Pl. 45d). The crags rose, but the lakes remained dull.

Suddenly in the early morning hours March 18 the lake crusts broke up, violent fountaining began, the lakes rose 40 feet in a few hours and united into one, and the pit overflowed its brim on three sides. The Red Solfatara rift cone became a standing fountain (Pl. 40c), destined to flood the entire south bay of Kilauea Crater for a week. An overflow on the Kilauea floor to the northeast swept down for a mile toward the Volcano House, crossed the trail, and made aa lava at its front. A branch flow at the east surrounded and burned the instrument hut.

SINK-HOLE CALDRONS

The gas release which followed the overflowing produced three sinkhole caldrons in Halemaumau. These developed enormous clusters of roaring fountains, hot greenish-brown fume, inrushing cascades, and such slaggy bombardment of the banks that big ramparts were built up. The new rim of Halemaumau was unrecognizable with these heapings (Pl. 44b). Whirlwinds were generated by uprush of hot gas, carrying fragments of lava crust hundreds of feet into the air, small tornadoes developed, and the fountains and burning gases were elongated into streamers of fire. Each whirl made a loud roaring noise, and large fragments fell several hundred yards from the pit. The whole region was so brilliantly illumined that newspaper print was readable at night 2 miles away.

END OF MARCH CRISIS, 1921

With the beginning of subsidence March 25, the lava of the pit cascaded into fountaining caldrons (Pl. 44c), the flows on the Kilauea floor pooled and backed up to the source cones, making slag heaps, and these finally collapsed on top. Quiet spells began to occur at the pit, and at the end of March 1921 there was a rapid sinking away of the whole lava column to the 100-foot depression level. This was the closing stage of the crisis, crags and lakes lowered 10 feet or more per day, the separate pools resumed their individuality, fume grew thicker, the noise, glow, and heat greatly diminished, and lines of traveling fountains like those of 1912 became conspicuous. Impressive underground chambers were revealed at the Red Solfatara cones on the Kilauea floor, and the outflow ceased.

SUBSIDENCE OF APRIL 1921

On April 3 the lava had sunk 185 feet in a week. An earthquake in the early morning of April 1 was felt all over the island of Hawaii. There was, however, no such swarming of earthquakes as occurred during the great subsidences. Only 26 local shocks were registered for April, all trivial except the one above mentioned. The lowering stopped about April 7, with stationary conditions at a depth 180 feet below the rim of the pit. There was now a large lava lake with numerous coves and islands and about 30 fountaining areas in action. The ordinary conditions of 1920 were resumed. The new spatter rims around the edges of Halemaumau, with steep outward slopes, covered with black glassy cinder and Pele's Hair, began to cave in. At the end of April the lake was 250 feet down, and the liquid was sinking 3 or 4 feet per day.

We may now pass somewhat more rapidly over the months during which the lava in Halemaumau rose and fell. May of 1921 the lava lowered 48 feet, some avalanches occurred, a pronounced earthquake was felt generally on May 19, fume increased, and the total number of open fountaining lava puddles among the crags decreased from 21 to 15. (*See* Part 4, map of August 13, 1921. Actually the March crisis was part of a steady subsidence.)

OVERTURNING OF CRAGS

A large crag mass at the north tilted until the ledge which had been the lake shore became a peak 100 feet above the lake, and down its flank was the wall of greenish-gray paste which had been the underlake slope.

This has happened a number of times in the experience of the Observatory and shows that in evolution of the tunnels and conduits, of the bench magma, the crags of solidified flow material occasionally become unbalanced and break away at their roots. They turn over in their supporting paste, like an iceberg undermined by its own submarine melting.

In June 1921, the lakes were increasingly solidifying, so that only seven or eight small puddles of fountaining lava remained open as blow holes in crust. The lowering of the month was 16 feet; for July the lowering was 22 feet. The maximum depression of the lakes was 338 feet.

RED SOLFATARA CHAMBER REHEATED BY OXIDATION

A most remarkable event of July 10, 1921, was the heating up of the underground chamber to incandescence at the Red Solfatara. This had been a flow tunnel in March. In June the interior was dark. Now it was a brilliant furnace, and the upper stalactite oven nearer Halemaumau also glowed increasingly.

The lava in Halemaumau, at about 334 feet depression, sank below the arcade (*see* Pl. 45 b) leading to the southwest rift. Immediately air was let into the wells, which are shafts upward from the ceiling of this arcade or tunnel. The air rushed up the wells noisily and changed the gray iron oxides of the glaze to brick red; this increased oxidation of the iron raised the temperature, and the tubes glowed.

Incandescent sparks were visible in the air blast at night. Within 4 days, wells and the flow tunnel were dark. Later the blast up the wells became violent and spasmodic, and red dust was thrown up. In August Halemaumau lava rose below into the arcade, choked the wells, and the air blast ceased.

RISING OF AUTUMNAL EQUINOX, 1921

During August the Halemaumau lava lakes rose 119 feet, inaugurating an equinoxial high level in September, to be followed by sinking in the autumn. The beginning of August showed liquid pools, mostly crusted over, 320 feet below the rim, with breaking crusts and scattered fountaining blow holes. The two blowing wells at the southwestern rift outside Halemaumau became hotter and stopped blowing, and glimpses down into the hole that underlay the upper oven revealed glowing lava 100 feet beneath. This liquid melt stood fully 200 feet above the lakes in Halemaumau, only 500 feet away and in connection through the tubes below. In the middle of the month the wells glowed after dark, puffs of blue-brown sulphurous vapor rose, and the rift crack again deposited sulphur and alum.

SMALL CHASM HOLDS LAVA ABOVE PIT LEVEL

Thereafter the lava column rose 3 feet per day, and an open vaulted rift chasm was visible in the wall of Halemaumau, where the rift below the outside glow wells emerged inside the pit. At the base of the wall, trickling flows poured out of the chasm into the lakes, from the lava in the chasm, blocked by its own crust, and standing vastly higher than the connected lakes of Halemaumau. Such are the effects of differential vesiculation, where an open pit permits a lateral frothing dike to squirt into it.

SHAPING OF A CRAG PEAK

At the end of August the lava was rising 8 feet per day. Finally the northwest crag in Halemaumau heaved high above its fellows and shaped itself into a cathedral spire 130 feet above the liquid lava. This shaping was accomplished by a process of upward tilting, compensated in the direction of overturning by the scaling off of avalanches. Spouting lava springs burst up about the edges of the floor of the pit at the very top of the debris slopes. These cascaded, and the area of black crusted flood enlarged at the expense of the crags and taluses, which had their footslopes covered.

During September the lava lakes rose 138 feet, and the crag peaks 158 feet. At the end of the first week in September these peaks appeared above the edge of the pit. There was a phenomenal lift of crags and islands, and a small flat island became in 3 days a big mushroom 47 feet high. The lakes reached 75 feet below the rim, and the highest crag 65 feet above the rim. The number of fountains increased from 7 to 150, showing gas and heat as functions of rising.

PICTURE OF HALEMAUMAU, SEPTEMBER 1921

The interior of the fire pit was thus a circular cluster of towering crags, surrounded by a ring pool of lava 20 to 40 feet wide (Pl. 45a). In the middle of what had been the main lake was now a deep canyon with channels leading off from it. In a chasm amid the crags a blowing cone exploded loudly and flung up splashes of lava shaped like umbrellas.

At the end of September the southwest rift cones outside the pit forecasted the coming subsidence by collapsing, and the lava inside the wells subsided lower than the lakes inside of Halemaumau, just as earlier they had risen higher. Also, within the lakes, the number of fountains dwindled from 45 to only 5, in the course of 4 days.

WINTER SEQUENCE, 1921-1922

Lowering of the entire inner landscape of crags and lava lakes characterized October and November. December held a low level more than 300 feet down for the liquid lava, and 1922 produced a gradual rising.

Rate of lowering was slow until the third week of October 1921, when it increased rapidly to 20 feet per day. The whole top of the lava column retained essentially unchanged features, including delicate rocky spires and balanced boulders. All was withdrawn into the depths, like the piston-head of an engine into its cylinder. After the middle of October the protruding crags were no longer visible from the Observatory. Earthquaking was roughly proportional to the speed of subsidence. The pit again became a place of noisy blowing cones.

Again the southwest rift oven outside Halemaumau became very bright, owing to a rush of air, when the arch of the rift cavern inside the pit, communicating with the well under the oven, was opened by the lowering lava column. The bottom of Halemaumau reached 330 feet depression.

CONNECTION PROVED BETWEEN PIT AND SOUTHWESTERN WELLS

In November the sinking slowed down, avalanches were frequent, and the lakes reached a depression of 366 feet. A remarkable event at the two open rift wells on November 19, outside of Halemaumau and 500 feet to the southwest, was an uprush or red dust and little stones from their openings, in sympathy with an avalanche that fell from the wall inside Halemaumau, at the point where the rift chasm joins the pit. This unmistakably proved connection between pit and wells.

December began with stagnant condition, fume had increased, in mid-month the lakes were 342 feet below the verge, a lava gusher appeared at the rift opening inside the pit, and at the end of the month this same rift arcade led straight away into the wall as a high, vaulted, narrow chamber, floored with a pool of liquid lava.

SPRING RISING, 1922

The rise of lava in Halemaumau from December to the March equinox of 1922 was similar to the rise of September 1921. There was the same general grouping of crags and lakes, the same welling up of liquid lava around the edges, and the same maximum of rising at the equinox. Rising continued at decreasing rates until May.

The gas action of this rising spell was singularly sluggish compared with the March 1921 effervescence. Violent caldron action was absent. Almost no spatter grottoes formed, and fountains were few. The usual method of gas release was by swelling a crusted pool to the rupture point and then emitting the gas by gentle breaking up of crust, engulfment of the slabs, and short-lived bubbling.

At the end of March 1922, the lava lakes were depressed 178 feet, at the end of April only 58 feet, and on May 12, 49 feet. At this time the highest crag was at the south, 73 feet above the rim of Halemaumau and 122 feet above the lakes. Again the crags had come into view from the Observatory. By the third week in April the scene at the lava pit almost duplicated the condition of October 1, 1921, and the vernal equinox had produced the same phenomena as the preceding autumnal equinox.

EASTERN RIFT OF KILAUEA OPENS

This pumping up and down of the great lava column had, however, opened a new crack in the flank of Kilauea mountain at Makaopuhi pit to the eastward. Accordingly May produced drainage into the deep eastern rift of Kilauea, not known to have produced outflow since 1840, except for the two pits immediately adjacent to Kilauea—Kilauea Iki in 1868, and Keanakakoi in 1877 (Dana, 1891; Brigham, 1909; Hitchcock, 1911). The southwestern rift of the outer mountain under Mauna Iki, which had been so active in 1920, remained sealed.

Early in May the two southwestern rift wells in the Kilauea floor again showed lava 50 feet below the openings, with a crust where gas was hissing through glowing cracks. In March the wall of these wells had been glowing brightly in daylight, but this upper incandescence had now ceased.

During the second week in May the liquid under the oven cone subsided, and again this cone heralded a crisis of sinking in Halemaumau, destined to be the greatest yet recorded by the Observatory. The drainage was to be by the east rift, but the sinkage showed here at the southwest rift. The rift athwart Halemaumau is all one fault fissure bounding a monoclinal fault step of which Kilauea Crater is the tread. These natural forecasts for the Halemaumau well, by what occurs in the mountain fracture outside, show certainly that the crater pit is an index vent for what actually is magma fill in a continuous crack.

GREAT SUBSIDENCE IN HALEMAUMAU, 1922

The crisis in Halemaumau began May 13, 1922, and in a week the lake level had dropped 300 feet, nearly equaling the rise of the preceding half year. The sinking was steady but majestic, most of the crags, lakes, and adjacent floors maintaining their identity. More molten lava was visible than during the rising period. Fumes remained thin, and seeing was good. Avalanches from crags and walls made an awesome crash, as tons of rock fell 100 to 300 feet. Pasty flows trickled from the veneer that covered the pit walls. Again the rift tunnel in the pit wall southwest was open when the lava column of the pit sank beneath it, and a blast-furnace effect was again produced through the oven well outside on the floor of the greater crater at the Red Solfatara; the interior surfaces of the oven became brightly incandescent as oxygen mingled with the uprushing volcanic gas.

Next came an unheard-of collapse of the pit, accompanied by incessant roar of avalanches falling into a tremendous void more than 800 feet in depth. After May 25 swarms of earthquakes were registered by the seismographs, many shocks were felt, and finally some were reported from Hilo, Honomu, and Waiohinu (Haw'n Volc. Obs'y, Bull., vol. 10, no. 5, p. 46, 57).

The new lava clinging to the Halemaumau wall caved away and made glowing avalanches, and the crags and lava lakes were enveloped in debris slope, though still identified, more than 600 feet down, on May 26. The huge cavern of the 1920 rift (Pl. 45b), gashing the southwestern inner wall of Halemaumau vertically, became a black tunnel half as high as the pit wall, with a lava pool inside the tunnel and incandescent rock falling from its ceiling. The extension of this tunnel appeared also on the northeast side of the pit, at a much lower level, and here also liquid lava could be seen in its depths.

CAULIFLOWER CLOUDS RESEMBLED EXPLOSIVE ERUPTION

In the early afternoons of May 26, 27, and 28, spells of general caving of the pit wall sent up brown and salmon-colored cauliflower clouds hundreds of feet high and made a thunderous roar. All surveying stations, signs, and portions of the trail around Halemaumau caved in. The tunnel southwest and the two rift wells fell in, making a smoking canyon that extended as a bay in the Halemaumau rim 500 feet in that direction. On other sides the rim caved in for a width of about 100 feet. The new pit was therefore a pointed oval in plan, with the point directed toward the Kau Desert, and was 2000 feet long by 1500 feet wide, whereas the former shape had been roughly circular, with a maximum diameter of 1400 feet. The new edge was 3714 feet above sea level, whereas the mean elevation of five rim stations after the building up of 1918–1921 had been 3732 feet; the loss of rim height was thus 18 feet. The bottom of the pit, a mass of convergent talus, later proved to be 861 feet below the rim July 6, 1922.

ENGULFMENT FORERUNNER OF 1924 EXPLOSIVE ERUPTION

This tremendous engulfment of the Halemaumau walls in 1922 was a precursor of what turned into a steam-blast eruption in 1924. The interesting thing about the comparison of the two was the clearly demonstrated outflow of lava in 1922, at a high level (2700 feet), in the interior of Makaopuhi Crater. No exterior drainage was seen in 1924, but everything indicated that this same eastern rift opened a way, out under the ocean, where a submarine flow occurred in 1924, and the sinking of the lava column below ground-water level generated the expanding steam.

If the explosive eruption were the product of steam in solution in magma, released by lowered pressure, this culminating lowering of 1000 feet in 1922, after the drops in height of 600–700 feet in 1916 and 1919, might have been expected to yield some sign of explosion, as should any such earlier crises. There should at least have been ejection of basaltic pumice, but there was not a trace of anything heralding steam explosion. This proves that the steam blasts of 1924 were occasioned by recession of lava below ground water and crateral plugging by infall (Jaggar, Bull. Haw'n Volc. Obs'y, Dec. 1924).

OUTFLOW ON EASTERN RIFT FOLLOWS HALEMAUMAU COLLAPSE

By May 31, 1922, Halemaumau became dormant, bottomed with slide-rock slopes, and the lava column had subsided at least 1000 feet below the rim level.

The outbreak at Makaopuhi pit was first observed at 8 p.m. May 28. This pit had been visited that same morning, and nothing unusual observed. It is the greatest of the dozen caldrons in the forest that lie in a line along the so-called 1840 rift and is the twelfth of the pits, counted from Kilauea. It lies 8 miles east-southeast from Halemaumau.

Cascades of stiff lava, during the night of May 28–29, poured from the top of the talus on the north side of Makaopuhi and made a pool in the bottom. Cracks across country had opened a foot or more, 4 or 5 miles west-southwest from Makaopuhi toward the Kau Desert.

NAPAU CRATER BECOMES ERUPTIVE

On the second day this eruption dwindled, but a new eruption of the same kind broke out 2 miles farther east-northeast, on the edge of Napau Crater, forming noisy explosive lava cones. Small areas of lava poured out, on the floor of Napau Crater, which is a wide shallow saucer, with a bottom partially covered with small trees. There were also small vents and flows on the plateau above to the east, and cascades poured down the cliff into the saucer. This eruption also lasted only a day and included a slight lava flow at a small pit crater northeast of Napau. All the lava of Napau and Makaopuhi, in this 1922 eruption, was a scoriaceous basaltic pahoehoe, with aa phases. New earthquake cracks broke across the country west-southwest from Makaopuhi toward the Kau Desert, breaking the soil freshly and emitting hot vapor.

EARTHQUAKES AND TILTING ACCOMPANY 1922 COLLAPSE AND OUTFLOW

At the Kilauea seismographs, harmonic tremors were marked during this eruption in the pit craters; some earthquakes had been felt by a surveying party south of Napau, but these were not felt along the rift extension, in the settlements, near the east point of Hawaii. (It was in this region the rift developed such extensive faulting and seismicity in April 1924.)

There was a strong tilt at the Observatory, first to the north-northeast, and then to the south-southwest, during the fortnight after subsidence began in Halemaumau; the south-southwest tilting toward the pit from the seismograph cellar became large, 11.4 seconds between May 27 and June 2. The cellar is 2.1 miles from the Halemaumau rim.

During May, 589 local earthquakes were registered, and about 80 of these were perceptible. These seismic and tilting phenomena, and the occurrence of this crisis in May (*see* Part 3), closely agree in kind and in season with the events of the later steam-blast eruption of 1924 (Finch, 1924).

HALEMAUMAU RECOVERY 1922–1923

The Halemaumau pit now showed walls lower than had been known before, with some dikes, notably on the southwest and northeast sides, and the lower rock was earthy, oxidized, and stained with solfataric salts. This staining confirms the conception of sulphur fuming of crateral rock. A long ledge trending north protruded at the southeast, and at the southwest corner a buttress pinnacle stood out from the wall, sulphurous smoke rose from the chasm where the rift wells had been, and a crescent of the rim had subsided to make a sunken inner bench. Southward tilting continued, and earthquakes were numerous in June. In July intense heat with sulphurous acid smoke began to appear at the line of the downsunken bench southwest which stood about 20 feet below the rim (Figs. 7–12). Then glow appeared at the top of the debris slope where the smoke was excessive and showed that live lava occupied the Kau Desert rift. The glow and debris slope were in the chasm that extended the pit to the southwest. The surface looked like a bed of coals for a length of 75 feet.

At 2 a.m. July 17 lava broke out at the top of the southeastern talus, 194 feet above the bottom of the funnel, poured down over the talus slope into the cup of debris, and formed a glowing pool 350 feet long which enlarged rapidly. The flowing and filling action lasted 4 days. Then the activity dwindled, and a quiet spell ensued. August produced avalanches which dusted the floor and obliterated the slaggy cascade of July. On September 2, in the forenoon a lava fountain appeared again at the top of the southeast talus, formed a cone about 15 feet high approximately 150 feet above the bottom of the pit, and five trickle flows made treelike forms down the talus slope with branches spreading out below. The flows spread over the July floor, and the source cone enlarged to a bell-shaped structure 30 feet high. The inflow of lava continued throughout September. A flat-topped lava slag heap was formed at the foot of the slope under the source cone, and by the end of September this heap covered up the older lake, bright trickling streams ran down its border slope, and a fountain on its surface built up a noisy grotto oven. The source cone remained high, glowing, flaming, and hissing about 50 feet above the new floor. The tiltings measured at the seismographs were now becoming northerly, or away from Kilauea, in accordance with the autumn habit of rising lava.

October produced gradual rising, with tumescence of the slag heap, a depressed lake inside it, and the southeast source cone about 30 feet above the floor. The pit in November had become a gigantic caldron with but little smoke by day and little glow at night. The bench lava northeast of the lake began to be upheaved. The floor area was now 1100 feet long by 900 feet wide, and the highest crag of bench magma stood 600 feet below the rim of the pit. The lake reached the level of its source vent November 16, and the ring-shaped floor began to be flooded from vents around the edge. The September source cone near the edge of the floor spurted and made a new slag heap. A horseshoe of glowing fresh lava developed around a dome-shaped uplift that contained the lake on its crest.

December inaugurated renewed rising of lava in big floods pouring from the southeast source cone, tumbling into the northern lake, and finally drowning the source cone under floods of its own slag. The southeast cone at the source of flows was gradually converted into a lake by the building up of a slag heap. During temporary sinking spells the shallow fresh pahoehoe lava of the pool rushed into a funnel well where the source cone had been. Aa slabs and flakes slid down the funnel slopes, red, pasty, and powdery. The material just below the surface of the whole pool was potentially a stiff aa paste. Except at the funnel no depression was produced by the drainage; all the outer part of the plateau pool resembled a mud flat. The funnel was 80 feet in diameter. The downrushing would last about 10 minutes, and then the liquid would rise again.

During December a flat, black floor developed with three lakes, and low crags which tended to become drowned under fresh flows. The whole bottom was rising 20 to 25 feet per week. The highest part of the bottom was 466 feet below the rim of the pit at the end of the year.

UNIFORM HEIGHTS OF MONTHLY RISING

Surveys the last half of 1922 revealed, for the months of rising lava in the funnel of Halemaumau, a tendency of the floor to rise about 76 feet each month. A similar tendency had been noticed in other years. As the funnel of the whole pit gets larger above, the gain per month is not uniform by volume but is uniform by height. This suggests a hydrostatic control, as though a larger shaft within Mauna Loa, connected with Kilauea, were filling at uniform rate. (*See* Part 4, discussion of hydrostatic effects.)

SUBSIDENCE AND RECOVERY HALEMAUMAU, SPRING 1923

The last day of 1922 the lava lakes sank leaving a black shelf and glowing scoriaceous aa inner walls. January 1 produced 55 earthquakes, and there was loud hissing in the pit. The southern half of the pit floor lowered 40 feet. In the first week a funnel developed with lowest bottom area 650 feet below the rim of Halemaumau. January 8, new pahoehoe flows began to trickle amidst the aa debris, and the sinking ceased. The southeast well had become a smoke hole. Snorting fiery cones were formed, flows made leaflike patterns, and by mid-month there was a fountaining lake covered by silvery crust. A strong earthquake January 14 did damage in Kau, the south end of the island. At the end of the month the floor level was crusted and rising, with brilliant breakings up of the shell.

In January the floor sank 31 feet, and in February the lava was stationary until the last half of the month. Thereafter and throughout March there was strong inflow, with different parts of the bottom rising 1 to 6 feet per day, and the floor 350 feet below the verge at the end of the first quarter of 1923. The March activity made two lakes on top of slag heaps, overflowing to fill border spaces, and on March 7 a remarkable gusher in the southeast lake sent up a lava fountain 80 feet high and 30 feet across, accompanied by half an hour of spilling over of the lake on all sides and down the flanks of its built-up dome.

On April 1 a vast inrush of lava covered the floor, an area of 28 acres, with an estimated volume of 200,000 cubic yards. This made the floor become level, 1400 feet in diameter and 308 feet down. A reaction with swarms of earthquakes restored to view two separate lakes and left a narrow black ledge against the pit wall around the whole floor. Then the two wells alternated in supplying new floods; sometimes 18 fountains were in action, and streams, cascades, and small islands varied the monotony of what was mostly a flat flood over a swelling floor. A wall pond formed by the floods from the lake overflows developed at the north. The behavior was as though the lake system tended always to keep itself at the top of a circular heap, whenever overflowing of the inner pools was in progress. April 25, another crisis of flooding occurred, with many bubbling fountains, flattening out all irregularities, followed by a mild lowering leaving a shore line in the form of a border ledge (Pl. 48a). At its highest the lava had been 235 feet below the rim of Halemaumau.

Rising continued during May, and fountaining, heat, streaming, cascading and whirlpool action reached a culmination, rivaling the displays of March 1921. The great fiery lake had not been so enormous since January 1894. It became 1700 feet long by 1400 feet wide. The fountains sent up milky-blue fume which was hot and suffocating on the leeward side of the pit. With temporary lowerings of a few feet the lake edge showed rounded lumpy ledges of dark glassy lava covered with black spatter. Only at the southwest rift chasm was there one small remnant of talus. There were 3 to 15 fountains, the larger number, at night, making bright greenish-yellow to rose illumination on the fume cloud above. An island with a whirlpool around it formed in the western lake. The rising was 5 feet a day, and on May 20 the liquid was 148 feet below Halemaumau rim and had risen 700 feet since the preceding July.

SUMMER CULMINATION AND LOWERING, 1923

The June behavior of the lava in Halemaumau was like what went before, with slight lowering making a 40-foot border shelf the first half of the month. Then rising was resumed, the lava lake was enormous, and tumultuous puffing and flaming fountains chased each other across the incandescent surface. Border fountains formed in elongated patches against the wall of the pit. The number of fountaining areas decreased. Strong currents rushed toward the big fountainings, where several groups of fountains would migrate into collision. There lines and swarms of bubblings sent up brown fume that turned milky above. At night flame puffs were visible, and there was vehement blowing and spraying. From bubblings at the southeast source well, a current carried wrinkling skins across the center of the pit, and on either side the streaming was against the wall, crushing the crusts, while zigzag bright lines formed, as the skin or scum tore asunder. A burning froth of spatter lumps that flamed yellow was seen June 5, the flames lasting for a minute or more and being repeated. Slabs of crust were piled around the edges of the lake. The afternoon of June 24 wall fountains showed spurts of red flame with brown smoke that curdled upward into blue fume. Elsewhere violet flame banners appeared, and large purple flames were noted as unusual. By July 6 the highest level was reached, 125 feet below the rim of the pit, submerging the one island.

The actual monthly gains had been 0 feet in February, 125 feet in March, 143 feet in April, 60 feet in May, and 40 feet in June, for the lowest portions of the floor. July showed a lowering of 30 feet. By July 9 the lake was 150 feet below rim and there was centripetal streaming at the southeast source well, a new characteristic. Then there were fluctuations, with more fountains during the risings; big arched grottoes formed at the lake border, and during sinkings there were avalanches, and a marginal shelf 50 feet high was formed.

LOWERING IN HALEMAUMAU

In July had begun what was to become, in August, an evacuation of the pit by another outflow on the eastern rift of Kilauea mountain, similar to the 1922 outflow and in the same vicinity. The lowering of the lava paste, however, jumbled about the wells, inside Halemaumau, was vertically only half as much as that of 1922 beneath the preceding highest level reached, and the drainage was more gradual. The bottom level reached was 3160 feet above sea level; in 1922 it had been 2860 feet. In

January 1923 the lowering was about 70 feet deeper than in August 1923, and both times the bottom was the same—aa paste, smoke holes, glow, many border shelves, and blocks of rock. The 1922 bottom had been wholly a funnel of talus from avalanches. At the end of the August 1923 collapses, avalanches sent up dust and were frequent, but nothing like the great engulfments of 1922.

The large lake, with fountains and much heat, about 215 feet below the Halemaumau verge, persisted until August 23. Earthquakes opened new cracks in the Chain of Craters region, north of the ones of 1922. Earthquakes, slides from Halemaumau walls, and lowering began August 22, a bright edge appeared around the lake, and after August 24 subsidence was pronounced. Pele's Hair was flying, fountains were puffing, a sluggish stream poured from the southeast source, fume increased, cracks shot up spray with a noise like a gun, and then the pit was bottomed by blocks between enormous cracks, and aa lava at one side.

CHAIN OF CRATERS OUTFLOW, 1923

August 25 steam and fume rose along a crack trending west-southwest in the forest, immediately west of Makaopuhi pit (the crater where the 1922 outflow occurred). Small flows of shell pahoehoe came up this crack (Pl. 47), puddled in two areas half a mile apart, with noxious sulphurous white vapor clouds up the crack in between. Each area produced two to three acres of lava. It was a true fissure eruption in a forest. The flowing lasted 7 days. Bright-yellow sulphur was deposited along the fissures. Flame holes were surrounded by aa spatter and coated with sulphur. The forest was killed by the gases, and brilliant yellow deposits of sulphur coated dead ferns and logs. The principal characteristic of this eruption was the cloud of irrespirable steam, charged probably with sulphuric acid, so that the western flow area was unapproachable.

In all 25 or more cracks were found crossing the Kalapana trail farther west, when that was explored June 21, 1924, but some of these may have been affected by the 1924 events. The fresher group was near Makaopuhi, and an older group near Alea pit. The cracks were 1 inch to 1 foot wide, and all broke the soil. Most of them must have been produced in 1922 and 1923.

RECOVERY OF HALEMAUMAU, SEPTEMBER 1923

Inflow in Halemaumau occurred near the southeast wall on September 4, depth of pit 565 feet, then another source appeared southwest of the center, and more lava flowed from a smoke hole at the south; on September 19 a source fountain appeared on the north side. Two pools southeast and southwest were defined by September 23. By the end of the month there was a third northern pool, and the depth of the pit was 398 feet to the lava surface. Fountaining was increased at times of subsidences.

RISE, OCTOBER 1923 TO FEBRUARY 1924

This equable rising of September inaugurated a refilling of the pit, almost perfectly repeating the history of February to July 1923. An examination of the two curves

(Pl. 76) shows 6 months in each case, with rising from the 3200-foot level contour to the 3600-foot level. In both cases fluctuation increased as the culminating levels were reached. The observed conditions and events were similar. In both cases a sea of lava with spectacular surgings was arrived at. In both cases the lowering at the end revealed a tumbled funnel of aa debris, and the curve in each case shows a sluggish recession in steps through 2 months of delay before the final crisis of collapse. After that all similarity ceased.

October 1923 at Halemaumau began with the lava lake depressed 388 feet and ended with it 313 feet down. There were the same pools and source wells, the larger lake was at the southwest, a cone had formed at the southeast, and slight sinkings were noted on 5 days. There were some small crags, and peninsulas; and an island appeared October 31, which shifted position in November (Pl. 48b) and was eventually joined by another islet. Fountaining was mostly at the source wells. At the end of November the main lake was 260 feet below the Halemaumau rim.

Oscillations started in December, amounting in single days to half the gain for the whole month. Spectacular cascadings were repeated at weekly intervals. Floodings drowned all islands and lake saucers, pouring in 10 million cubic feet of lava in half an hour and making continuous surfaces of 40 acres. Tumultuous fountaining was followed by rapid subsidences, and some source wells became sinkholes. The range of vertical fluctuation in single days was 30 to 60 feet. The depression at the end of 1923 was 219 feet.

January 1924 (Pl. 48c) continued the same weekly fluctuations, so that on January 21 the depression of the lava flood was only 114 feet below the Halemaumau rim, and fountains spurted 100 feet high. The lava remained high January 18 to 31 and then cascaded into the north pool. These wells acting as sinkholes changed; January 5 the southeast well received the drainage, and before that a cascading took place from the north pool into the main lake. On January 18 the lava rose 65 feet in 16 hours, whereas the subsidence of January 31 was 28 feet.

PHASE OF EXPLOSIVE ERUPTION, KILAUEA, 1924

COMPARISON OF 1922, 1923 AND 1924 CULMINATIONS

There were four risings followed by significant drainages, in Halemaumau pit, beginning November 1921 (Pls. 74, 76).

November 1921 to May 1922, the lava rose steadily 300 feet until the liquid was only 49 feet below the Halemaumau edge. Then came the Halemaumau crash to 861 feet, and the Makaopuhi outflow miles away. June was a dead month.

July to December, another 6 months of rising, 350 feet, until the liquid was 466 feet below the edge. Then a sharp drop to 650 feet in January 1923. The dead period lasted a week. We may infer from the earthquake centers that the lava, which retreated, made an intrusion in the eastern Kilauea rift.

February to July 1923, another 6 months of rising 500 feet, until the liquid was 129 feet below the edge. Then a delayed drop of 2 months to the August collapse of 1923, depth 565 feet, accompanied by the East Rift fissure outflow. The dead period lasted 8 days.

September to February 1923–1924, another 6 months of rising 450 feet, until the liquid was 114 feet below the edge. Then a still more delayed drop of 3 months, to the final collapse and engulfment of the explosive eruption in May 1924, to depth 1335 feet. The dead period lasted 2 months. Lava returned to Halemaumau in July.

The striking parallelism of these successive steady risings and paroxysmal sinkings, two of the latter accompanied by East Rift outflows and one by East Rift earthquakes, made it reasonable to look for East Rift breakage and signs of outflow in the great crisis of April-May 1924. The breakage and earthquakes definitely arrived. The outflow almost certainly occurred and was submarine.

FEBRUARY-APRIL RUPTURE, 1924

The breakage of the East Rift, extending the 1922–1923 fractures 25 miles farther east to Kapoho, preceded the explosive eruption. This event produced conditions where an explosive eruption was inevitable. It opened a void below the water table for retreat of lava and engulfment of walls. This void created steam-geyser action. The great length of the rift block and the great volume of materials removed and of the vacated pit all exceeded anything hitherto observed at Kilauea since 1840 or 1823[8]. Both these former occasions produced visible lava flows close to sea level and pouring into the sea, but with vents above ground-water level. The May 1924 collapse at the crater was led up to by breakage of the East Rift, eruption up its pits and fissures in 1922 and 1923, and further breakage far to the east in April 1924.

This breakage had begun in February and March 1924. February continued rapid fluctuations in Halemaumau, with gigantic fountains 150 feet high that flung light spatter pieces 6 inches long over the Halemaumau rim. Depression of lake below rim was 130 to 140 feet. Cascades into sinkholes, of 40 feet fall, alternated with floodings. The roar was like a heavy surf. Lowering dominated over rising, and by February 21 the lava was 380 feet below the rim. Small pits showing aa paste on their slopes were left at the source wells, the benches clung to the walls, small avalanches fell, cracks back of the Halemaumau rim widened, dense fume was belched up the north and south smoke holes or source wells, small lava trickles with dull glow poured amid the debris, but after March 1 no molten lava was seen. Glow persisted throughout March at the inner vent southeast, the floor remained unchanged, and fume from the wells obscured the broken and tumbled blocks.

KAPOHO CRISIS

At the Kilauea Observatory seismographs 36 earthquakes were registered in February, 78 in March, and 358 in April. The measurable seismometric distances to earthquake sources indicated migration of these sources eastward along the East Rift —that is, farther and farther from the Observatory, up to 30 miles. This was cor-

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[8] To persons unfamiliar with the Kilauea-Mauna Loa half of Hawaii, it should be pointed out that the water table is near sea level, excessively low, and the only springs are at the shore line. In 1823 a fissure low on the mountain drained Kilauea by lava flows at Kapapala and Mahuka: when the lava receded steam explosions strewed rock fragments beside the fissure, at two places 280 and 700 feet above sea level (Stone, 1926a; Stearns, 1926; Haw'n Volc. Ol'sy, Bull., vol. 12, nos. 5, 11, figs. 40, 41).

roborated by felt earthquakes, the first shocks felt by a Survey party near Napau Crater, then by an alarming earthquake generally felt in Puna, the east district, then by a series of menacing shakings and subterranean noises in the hills there back of Opihikao, and finally 88 felt shocks at Kapoho (map, Fig. 14) April 21–22, and several hundred shocks with rumbling and cracking of the ground along 4½ miles near Kapoho April 22–23. The cracks were a few inches to 3 feet wide (Pl. 49) and trended with the rift along a belt of country east-northeasterly, extending themselves under the sea. The shore line here sank 12 feet for a north-south length of about 1 mile. Releveling from Kula Quarry to Kapoho showed a maximum lowering of 9 feet (Finch, 1924; Haw'n Volc. Obs'y, Bull., vol. 12, no. 4, p. 19).

HALEMAUMAU DURING APRIL RUPTURE

The bottom of Halemaumau pit was smoky in April 1924, from 375 to 400 feet below the rim, and some glow appeared in cracks and at the southeast well. A northern rim station fell in about April 19. April 20 there was avalanching, sulphurous fume was strong, and glow was not detected. April 23, the day of maximum earthquaking and rupturing at Kapoho, glow returned, which became brilliant the next night at the southern vents; light pink color flared in sympathy with noises of splashing lava. At the end of April the northeastern part of the bottom subsided to a funnel with orifice 500 feet down, there was constant rattle of small avalanches, and red-hot crumbly lava peeled off the side of the southeast vent hole.

GROUND TILT TOWARD KILAUEA CRATER

In January 1924, the tilts at the Observatory involving a southern component amounted to 7 seconds, in February 14 seconds, in March 13 seconds, in April 13.5 seconds, and in May the south tilt was 59 seconds, the directions becoming increasingly due south and south-southwest. (*See above*, 1922 collapse.) Resolved into its independent south and west components, the south tilt amounted to 88 seconds from January to June 19, with 69 seconds of this after April 29. The westerly component that started February 26 and stopped June 17 tilted 32 seconds; 27 seconds of this was after April 28. Combining 88 seconds south with 32 seconds west we get a tilt of about 95 seconds, S. 20° W. Halemaumau is S. 48° W. from the Observatory. The direction S. 20° W. is toward the eastern half of Kilauea Crater, from the Observatory to a point midway between Halemaumau and Keanakakoi pits, and at right angles to the trend of the north wall of Kilauea Crater. (For tilt diagrams *see* Plate 87.)

HORIZONTAL DISPLACEMENTS

The vectors of horizontal displacement shown by Wilson's (1935) triangulation, for points outside the inner floor of Kilauea, indicate horizontal movements of 3 to 5 feet, occasioned by the 1924 collapse, toward this region immediately west of Keanakakoi pit. Two points inside the Kilauea floor moved toward Halemaumau by like amounts.

LOWERING OF KILAUEA DURING COLLAPSE

This same investigation by Wilson shows that careful levelings compared for 1921 and 1927 reveal a lowering of Kilauea Crater, with reference to mean sea level, of 3 feet 2 to 4 miles away from the center of the pit, and of 13 feet at a bench mark on the Kilauea floor east of the Halemaumau rim. The inner fill of Kilauea Crater thus lowered greatly, but the outlying country a mile south of the Crater also lowered 6 to 8 feet. The Observatory and the Volcano House subsided about 3.6 feet. The whole rift belt, which approaches the crater from the southwest and bends eastward through Kilauea Iki to merge with the East Rift, was probably affected by the collapse of 1924. The tilting of the wall on the north side of the rift belt, where the Observatory is in a direction S. 20° W., was thus toward the seaward drag of the subsiding southern blocks, rather than toward Halemaumau alone. The 3961 earthquakes, registered in May 1924, were occasioned partly by this dragging and slipping, partly by the rushes of confined steam, and partly by the shock of avalanches of engulfment.

LOWERING OF WHOLE MOUNTAIN

The lowering of the mountain was not limited to the crater. Leveling in 1922 and 1926 from the tide-gauge at Hilo to the Volcano House at Kilauea exhibited the following changes in bench marks along the 30 miles of road going northeast down the mountain:

Place	*Distance from Halemaumau* *Miles*	*1926 Elevation* *Feet*	*Change between 1922 and 1926*
Volcano House	2.3	3972.54	Down 3.56 feet
Park Boundary (Crater Hotel site)	2.9	3820.75	Down 3.09 feet
Mountain View	13.0	2002.62	Down 1.08 feet
Olaa- Fifteen Miles B.M.	16.5	1266.48	Down 0.75 foot
Olaa Twelve Mile School	19.2	764.59	Down 0.54 foot
Olaa Keaau Station	21.7	359.32	Down 0.32 foot
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These figures appear to be, when plotted, "an ideal deflection curve suggesting how downward displacement increases rapidly as Halemaumau is approached" (Wilson, 1935, p. 50). The rim bench mark of Halemaumau itself lowered 13 feet, flexing the curve down sharply in going from Volcano House to the pit.

MAY EXPLOSIVE ERUPTION, KILAUEA 1924

The diary of this eruption is presented in Part 3. It has been described by several authors (Haw'n Volc. Obs'y, Bull., 1924; Jaggar and Finch, 1924; Finch, 1924; Stearns, 1925). Intensity curves of its features have been given (Haw'n Volc. Obsy., Bull., May 1924, Fig. 16) as well as a discussion of its volume relations (Haw'n. Volc. Obsy., Bull., Dec., 1924). We shall treat it here in relation to our diagram of changing depths of Halemaumau (Pl. 74) without any lengthy discussion.

April 28 more earthquakes came to Kapoho. In Halemaumau avalanche material continually rolled into a northeast funnel. Early in May instrumental frequency of earthquakes increased. Harmonic tremor suggested lava surging.

May 11 Halemaumau threw out rock fragments in the midst of avalanche clouds. During the following week steam blasts from the depths were rushing up at intervals, as the avalanches tore down the walls of Halemaumau pit. The intervals averaged roborated by felt earthquakes, the first shocks felt by a Survey party near Napau Crater, then by an alarming earthquake generally felt in Puna, the east district, then by a series of menacing shakings and subterranean noises in the hills there back of Opihikao, and finally 88 felt shocks at Kapoho (map, Fig. 14) April 21–22, and several hundred shocks with rumbling and cracking of the ground along 4½ miles near Kapoho April 22–23. The cracks were a few inches to 3 feet wide (Pl. 49) and trended with the rift along a belt of country east-northeasterly, extending themselves under the sea. The shore line here sank 12 feet for a north-south length of about 1 mile. Releveling from Kula Quarry to Kapoho showed a maximum lowering of 9 feet (Finch, 1924; Haw'n Volc. Obs'y, Bull., vol. 12, no. 4, p. 19).

HALEMAUMAU DURING APRIL RUPTURE

The bottom of Halemaumau pit was smoky in April 1924, from 375 to 400 feet below the rim, and some glow appeared in cracks and at the southeast well. A northern rim station fell in about April 19. April 20 there was avalanching, sulphurous fume was strong, and glow was not detected. April 23, the day of maximum earthquaking and rupturing at Kapoho, glow returned, which became brilliant the next night at the southern vents; light pink color flared in sympathy with noises of splashing lava. At the end of April the northeastern part of the bottom subsided to a funnel with orifice 500 feet down, there was constant rattle of small avalanches, and red-hot crumbly lava peeled off the side of the southeast vent hole.

GROUND TILT TOWARD KILAUEA CRATER

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May 11 Halemaumau threw out rock fragments in the midst of avalanche clouds. During the following week steam blasts from the depths were rushing up at intervals, as the avalanches tore down the walls of Halemaumau pit. The intervals averaged

12 to 24 hours the first 3 days, 2 hours May 13, 6 to 8 hours May 14 to 23, 12 hours May 24–25, and 24 hours May 26–27.

This suggests geyser action, first slowly developing a small steam boiler, then intense heat, renewal of water, and short intervals, then a larger chamber with more inflow of water and longer intervals, and finally a return of sluggish lava in the depths, shutting off the water until steam rush became steam seepage. There was no evidence of chlorine; it was fresh-water steam.

DEEPENING PIT

May 7 the bottom of the debris funnel in Halemaumau appeared more than 600 feet down. May 11 the talus seen was estimated at 700 feet down. May 15, by sound-travel methods, the depth of the pit was estimated at 1350 feet. May 17 the great enlargement of the upper walls had choked the bottom to make a flat, estimated by actual inspection at more than 1000 feet down. This was when the eruptions were most intense, about three each 24 hours, and the steam expansion had to find a way through great accumulations of engulfment. Surveys after the explosions were over, the first week in June, made the bottom of the funnel of avalanche fragments 1330 feet down. (*See* Plates 76, 82.)

SEQUENCE OF EXPLOSIVE EVENTS

The sequence for the 18 days from May 10 showed 5 days of short interval preliminary explosions, with about 100 earthquakes a day, 10 to 20 of them felt, spasms of explosion increasing in length, falls of stones observed from a distance on May 13 and 14, explosive intensity notably increasing with the frequency on May 13.

Beginning May 15 came 6 days with big explosions three or four times a day; intensity increasing steadily (Pl. 50a) to May 18 (the climax), declining thereafter; observed falls of stones (red hot at night) and duration of explosive spasms reaching a maximum on May 19; electric storms very powerful May 17 to 19; earthquakes, 150 to 200 per day, and 20 to 30 of them felt.

The end period of the eruption, May 20 to 27, showed increase in number and intensity of earthquakes until there were 350 to 450 per day May 22–24, declining thereafter; other features declined (though there was a small revival of explosions on May 24) with the exception of caving in of the rim of Halemaumau, which reached its maximum May 21 and 22, 3 to 4 days after the maximum of explosions, and coinciding with the maximum of *felt* earthquakes.

Large rocks (Pl. 52) were thrown up 3000 feet, and cauliflower clouds boiled up more than 6000 feet. Fine material fell to leeward with the trade wind—namely, to the southwest. Boulders flung out (Pl. 51b, d) were old rock matter from the walls, some of which was red-hot hard intrusive material, from dikes and incandescent sills. The boulder barrages left the largest accumulations crosswise of the rift belt, northwest and southeast. The observed caving in of the rim during the eruption moved counter-clockwise from the southwest in the early days, to south, to southeast, to northeast, and finally to all sides.

VOLUME RELATIONS

The actual thickness of beds of gravel on the rim of the pit was 17 inches; of ash half a mile away 2 inches, a mile away 1 inch, 11 miles away to leeward 0.1 to 0.2 inch, and at Pahala, 25 miles away, a mere film. Some grit fell in Hilo 29 miles to windward. The ash was in many places pisolitic from mud rains.

Taking the area and depths of the pit aperture before and after the eruption at Halemaumau, and adjusting the figures for computation by volume of cylinders, we may estimate that the visible rock walls lost 202 million cubic meters. The amount of this that lay on the surface of the country after the eruption was the equivalent of 793 thousand cubic meters of rock. Deducting what explosion ejected from what was removed from the visible pit, we get at least 201 million cubic meters to be accounted for as engulfed into a void beneath the pit. This amount is 253 times the amount ejected by explosion, without counting pore space or breakage beneath limit of vision.

The engulfed material followed downward the retreating lava which had filled the pit. Presumably, therefore, a lava flow of not less than 201 million cubic meters poured out on the eastern rift of Kilauea below sea level, where the depth of the ocean is very great. Nothing of this would be perceptible to man in such deep water (Haw'n Volc. Obsy., Bull., Dec. 1924).

MISCELLANEOUS PHENOMENA

Harmonic tremor at the seismographs, characteristic of lava surging, was recorded until May 16. Earthquakes accompanying the explosions showed a peculiar continuous tremor, making a characteristic graph of an explosion. Air concussion was felt with the larger explosions. Avalanches enlarged the pit, increasing its radii about 750 feet on all sides. The circle of coarse debris around Halemaumau had a radius of half a mile. The rocks had no trace of contemporaneous lava, many were crystalline, some showed signs of surface heating, many were gabbroid intrusives, and some of the explosions seen after dark exhibited incandescent fragments (spoken of in the Diary (Part 3) as "hot rocks"). Cracks concentric and radial to the pit were developed, with much steaming. Noxious fume was absent. Hydrogen sulphide could be smelled, a new feature. As the cauliflower clouds dwindled, rushing white steam replaced the dust-charged vapors (Pl. 50b). Luminous flashes inside the pit were common during eruptions, and electrical phenomena were so strong that a shock was felt if a motor-car was touched. Heavy falls of ash on the foliage were relieved by rainstorms, which washed it off.

PERIOD FOLLOWING EXPLOSIVE ERUPTION, 1924

Halemaumau pit had become an oval caldron more than twice its former diameter (Pl. 85, map of Kilauea). It was 3400 feet long northeast-southwest and 3000 feet wide. Intrusive bodies in the bedded lavas of the walls were more numerous at depth. A dozen dikes cut the lower walls (Pl. 51c), especially northeast-southwest. Caverns on these dikes southwest were the 1920 feeders of outflow. Avalanches and earthquakes were numerous in June, and purring steam through the bottom gravel was frequent (Pl. 51e). The evening of June 12 showed glow, due to caving away of the long "canoe sill", 600 feet below the north rim of the pit, and the sill's incandescence was demonstrated. Powdery slides of red-hot stones collected in a fiery talus. The broken wall (Pl. 51a) would quickly cool to cherry red, purple, and black. There were similar glowing intrusives at the west and northeast. Some glow remained visible in these intrusive bodies for a month. Seismic conditions became nearly normal the end of June, and all motion decreased.

PHASE THAT BEGAN CYCLE 1924–1935

RETURN OF LAVA TO HALEMAUMAU

There was by survey a diamond-shaped lowest part of the bottom flat, 1335 feet below the east rim (Pl. 82a). After mid-July mild blowing noise was heard. Just after noon July 19, 1924, liquid lava broke through the western talus and flowed for the remainder of the month. It brought gas with it and made a spraying fountain. This threw up Pele's Hair and pumice and built a cone 100 feet high. The liquid developed pahoehoe transformed to aa, flowed down the slope, and made a fill in the bottom 25 feet thick, 1100 feet long by 800 feet wide. Flowing dwindled during July, and the floor showed glow cracks in August.

REVIEW OF CYCLE 1913–1924

That this was the end of a true complete cycle is clear from Plate 74. There was a low dormant year at each end, 1913 and 1924–1925. The July inflow of 1924 may pertain to the new cycle following or may be the end of the old. Perhaps it is more logical to date a cycle from the lowering that ends the main evacuation of the pit. (*See* Plates 74, 86.) This would take us from May 1913 to June 1924, approximately 11.1 years. The July lava of 1924 then becomes an incident of the new cycle, inaugurating the dormancy of 1924–1925. It is the reaction from the depths of the extraordinary engulfment-evisceration of the explosive eruption. It reasserted a lava bottom to the pit and an end of the abnormal conditions that created steam. Such a lava bottom, hot and glowing, existed in 1913.

Wilson (1935) has shown engineering evidence that Kau Desert versus Volcano House relatively, and Volcano House versus Hilo probably, increased in elevation between 1912 and 1921. Tilt instruments in 1918 confirmed excessive tumefaction. The swelling of Kilauea mountain top ended in 1919, the peak of the overflow period of both Kilauea and Mauna Loa. This agrees with tumescence of Sakurajima and Usu volcanoes, as expressing magmatic culmination (Omori, 1914–1922, 1911–1913–1920). The cycle of lava outpouring is also a time of heat uplift or thermal expansion, ended by collapse.

LAYERING VERSUS FREE LAVA COLUMN

As shown on Plate 76, which expresses lowering lava of 1924 by months, and the period 1925–1934 by years comparable with the height of lava on December 31 of 1924, these successive years added layers to the bottom of Halemaumau pit. (*See*

Plates 82, 83.) So July 1924 placed a layer of lava on the gravel bottom. The cycle before 1924 did not proceed by layering. The lava column was alive and pulsating, duplex in its division into liquid and bench magma, but free to move up and down.

This July veneer of basalt that solidified on the bottom was entirely different. Some incorporation, digestion, or solution of the column of boulders and debris engulfed would be necessary now, before the filament of lava that worked its way through the crevices could be called a "lava column". When that condition arrives in the future, pulsations of subsidence may be expected (Pl. 75 to first half of Pl. 76).

There were no subsidences 1924 to 1934, other than surface shrinkage, though there were eight inflows at Halemaumau and two eruptions of Mauna Loa. In the former cycle, the three eruptions of Mauna Loa were followed by subsidences at Kilauea. And there were then numerous subsidences at Kilauea otherwise accounted for. The explosive engulfment of 1924 plugged the shaft, deep down, with a breccia. This fill of fragments had not yet been lubricated with free-moving magma in 1944.

SUMMARY OF THE CYCLE

The cycle of 1913–1924 began with slow rising melt in Halemaumau, a summit eruption of Mauna Loa, steadily rising inflow at Kilauea after a temporary setback, a southwest outflow at Mauna Loa, another setback at Kilauea 400 feet in a day, an immediate recovery, and then building up of lakes, platforms, and crags until Halemaumau overflowed on the Kilauea floor.

This continued through 1918 and 1919, when Mauna Loa made another outflow southwest, and Halemaumau lowered its lava 600 feet in one morning when Mauna Loa finished. There was recovery in a month to the top, however, then Kilauea entered the field for outflows, starting southwest in 1920, entering the crater for gushing overflows in 1921 and 1922, then crossing the crater to the northeast rift for two more flank eruptions in 1922–1923. The year 1919 had been the peak of the cycle for Kilauea and Mauna Loa (Pl. 74).

The lava within the rift, which splits Kilauea Mountain from southwest to northeast, had wedged the mountain open, and in 1924 the splitting was complete. The mountain yielded, the lava which had surged up and down in Halemaumau at the bend of the rift, with incomplete flank outflows, could now flow out under the sea somewhere down an 18,000-foot slope. The east point of the island executed a graben fault along the fissure system as the rift belt opened, Halemaumau collapsed, the internal lava effervesced in contact with a flood of ground-water gushings, and geyser jets were added to avalanching engulfment.

The flow of lava on the ocean floor slowly froze and backed up, the pit shaft choked, the steam abated, the lava rose and shut off the water springs, and the path of rising was through the interstices of the Halemaumau crater breccia, about 40 feet a day from below sea level (Haw'n Volc. Obs'y., Bull., vol. 12, no. 12, p. 118). It reached the top of the rocky fill in 2 months, released its gas in presence of oxygen, fountained and trickled for 11 days, and was still. It had filled the Kilauea pores, and now by a devious pathway underground its next task was to back up under Mauna Loa and show itself there in 1926.

REPOSE PERIOD 1924-1926

The end of a cycle is followed by short repose, here treated as part of the next cycle. Interpretation of repose, to the writer, is temporary satisfaction of intrusion necessities, for perpetual rising magma, occasioned by the structure yielding. The yielding in 1924 at Kilauea was horizontal enlargement, by openings along the rift in depth. The surface area around Kilauea Crater contracted apportionately to subsidence of graben fault blocks. This did not prevent the much greater mountain under the sea from expanding southeastward. Probably the fault blocks on the shoreward side glided seaward and opened the dike fissures of the rift belt.

When the lava of the northeastern rift dike backed up to appear in Halemaumau, the pit bottom congealed, and the rift magma continued its progress through the deep plexus of rifts and cross fractures that leads toward Mauna Loa westward from Kilauea, or perhaps the Manua Loa column was steadily pressing. This was confirmed by notable earthquakes centering in that direction in August and September, 1924.

The Hawaiian volcanic system was without lava activity for 20 months from August 1, 1924, to April 10, 1926. It was not inactive seismically. At the Observatory in 1924, from August to December there were 90, 116, 106, 51, and 169 earthquakes. The increases at equinox and solstice are conspicuous. The unstable walls of Halemaumau, after the great enlargement and deepening, avalanched apportionate to the numbers of earthquakes. The northeast wall, over the red-hot columnar sill, was nearly vertical and appeared particularly uneasy. It enlarged more than any other part of the pit rim.

The glowing floor of July gradually cooled off. Earthquakes were intense in Kau district. Blowing noises and smell of hydrogen sulphide were noticed. Avalanches were at the west, northwest, north, northeast, and southwest, the last two where the rift belt crosses the pit, and the northern slides always dominant. The blowing, apparently at the July cone vent, ceased in November. There were dust storms in the 1924 ash of the Kau Desert.

A big shock, centering on the north rim of Kilauea Crater and cracking the ground there, recalled parallel events in 1913, the next preceding repose year. On both occasions the shock was in late October, and in both repose years the collapse had come in May, with lava revival in July.

Though there were spells of extreme quiet in November and December, there was excessive northern and western avalanching in Halemaumau November 20. This made a landslip in the great western talus slope, which obliterated the lava cone of July and buried half the lava floor. The bottom was thereby raised from depression below rim 1305 feet to 1280 feet (Pl. 82). After this adjustment of bottom debris there were times of complete stillness in the pit. There were dry hot places and sulphate stains. The December increase of earthquakes renewed northern sliding, and in December the graduated frequency of quakes to solstice was shown by the numbers per week: 19, 41, 50, 33, 30.

Local earthquakes and slides lessened in 1925. The monthly frequencies of quakes were 94, 94, 79, 70, 83, 51, 109, 94, 102, 51, 50, 48. Only the July and September increases suggested solstice and equinox effects. March and December showed declines. There were numerous falls of rock from Halemaumau rim, slides from every direction, but with more northeast and north than anywhere else. A certain class of seismic records, which waxed and waned evenly, came to be called a-seisms, because definitely caused by avalanches: whereas earthquakes of the same amplitude, classed as very feeble, definitely started avalanches and had more abrupt beginnings, with sharp phases. July produced numerous earthquakes centering under southern Mauna Loa slopes. The end of the year was quiet.

The first quarter of 1926 cannot be said to have heralded the April outbreak of Mauna Loa. There were more felt earthquakes; the last quarter of 1925 had one or two per month, whereas in 1926 January had 6, February had 6, and March had 9 January showed increase of avalanches in Halemaumau: those of January 19 coated the floor of Kilauea Crater with red dust, and pellets of mud rain fell at the Observatory. There was an earthquake on Mauna Loa February 28, and on March 19 a large earth-quake occurred on the ocean floor 80 miles northeast of Kohala. This was felt in Honolulu.

SUMMARY OF REPOSE PERIOD

The most conspicuous single events in the repose period were the October earthquake and November avalanche of 1924, both at Kilauea; the July Mauna Loa spasm of earthquakes in 1925; and the big sea-bottom earthquake of the Hawaiian Islands fissure system in March 1926. These were at intervals of 4 months, 7 months, and 9 months within the period, and each involved a larger, and less local, unit of earth crust. The last preceded the Mauna Loa eruption by 22 days.

Probably the stress of magmatic pressure shifting from Kilauea to Mauna Loa, a larger and higher center of tumescence, finally involved the island block in movement, in order to bring about the final rupturing of the Mauna Loa rift, which had been sealed since November 1919.

PHASE OF ANNUAL ERUPTIONS, 1926–1932

MAUNA LOA ERUPTION, 1926

About 3 a.m. April 10, glowing lava spouted along the upper 3 miles of cones and pits of the Mauna Loa rift belt, immediately south of Mokuaweoweo, the summit crater. The actual beginning shown at Kilauea by seismographic tremor was 1:36 a.m., followed by two pronounced earthquakes. A crack only 1 to 3 feet wide opened southward from a point tangent to the east edge of the bottom of the south pit of Mokuaweoweo, vomited out pumiceous silvery pahoehoe froth lava, and extended itself S.30°W. past the next two pits and over the brow of the mountain down to an elevation of 12,400 feet. The block of country east of the crack was faulted down 2 or 3 feet, the crack making a step.

Three flow tongues poured southeast from the crack, originating 1, 2, and 3 miles from Mokuaweoweo; their lengths were $\frac{3}{4}$ mile, 2 miles, and 4 miles, and the last, making aa, reached down toward Pahala to an elevation of 9250 feet. If this flood had kept going it would have destroyed the Hawaiian Agricultural Company reservoir at Wood Valley in a few hours. Fortunately the main gushing of this first phase ceased about 8 a.m. the same forenoon, after flowing 5 hours.

The under-magma was opening the southwest rift (Pl. 63a), which even on April 10 was fuming at an elevation of about 8000 feet, along cracks half a mile or more east of the 1919 source crack, and 11 miles down the mountain from the upper outbreak. Here three cups on April 13 were emitting dense yellow-brown fume, and this developed into a line of 30 spouting lava cones (Pl. 63b) downhill from an elevation of 8000 feet to 7050 feet, a length of 4 miles, to a place about 1¼ miles uphill from Puu o Keokeo.

The first stream here overflowed the 1916 lava in the direction of Waiohinu, south-southeast, for 7 miles, to an elevation of 4300 feet. The source was flooding the plateau above Puu o Keokeo, as usual, with glowing pahoehoe lava, April 14 and 15, and some of the tongues of lava found their way westward into the Honomalino woods. The vent crack was splitting itself open downhill. The source pahoehoe changed itself by stirring into scoriaceous aa (Pl. 63c) half a mile from the vents, and the southeastern flow was aa where it stopped April 16 at the glade called Pele o Iki.

This eruption repeated the events of 1916 and began at an uphill extension of the 1916 crack. As in 1916, the Honomalino flow to the west finally dominated, but in 1916 it reached the sea. This was also aa.

This western flow pushed down the steep forested slope of South Kona 2 to 3 miles south of the 1919 flow, and parallel to it, entering the sea at Hoopuloa. It crossed the belt road at 12:22 p.m. April 16, 3 miles above Hoopuloa village. It was progressing 7 feet per minute. April 17 it was filling a hollow of the shore platform back of the village (Pl. 62a), maintaining a front 1500 feet wide. Its average advance was 2.7 feet per minute.

At 4 a.m. April 18 it started burning the outhouses of the village (Pl. 61a). It reached the sea (Pl. 62b) at 6:30 a.m. By 8:30 a.m. the harbor was buried, the village destroyed, and fish were killed by thousands within a light-green belt of turbid water that encircled the front at a distance of half a mile. The vertical thickness of the flow was about 40 feet (Pl. 61b). There were roars and steam explosions. The distilling vegetation within the flow made odors of ammonia, and the sea water developed chlorides (Hawaiian Volc. Observatory, Bull. and Volcano Letter, 1926).

It stopped forward progress (Pl. 62c) at the sea front by 9 a.m., April 18, but at the roadway, farther up the mountain, sluggish flow of a stream within the rough lava fields continued for 24 hours. Still higher, at the tree line, new arms from the source penetrated cattle paddocks farther north than the first stream, and action continued at the source region until April 30. There were some lava lakes of pahoehoe along the source crack. In general the liquid was more viscous than that of 1919. The aa fields were clotted with concretionary balls, not found on the 1919 flow. Yellow sulphur crystals developed on a part of the vent fissure. Spatter cones along the crack were in lines, 50 to 75 feet high with craterlets, the material frothy basaltic pumice. There was marked opening of the rift southward and downhill from April 17 to 19. This action had robbed the higher vents of their lava supply. These higher orifices had fed the eastern flows. The last tongues in action in the upper ranch paddocks of Honomalino were those farthest south.

SEISMIC EVENTS OF MAUNA LOA ERUPTION, 1926

The number of earthquakes recorded for April was 671 (compared with monthly average of 52 for the preceding 3 months). Eighty-five of these were felt. There was close seismic resemblance to 1916, which had produced over 600 shocks, as contrasted with Mauna Loa in 1914 making only 60 shocks, and 1919 making 185. The time intervals between beginning of summit activity and beginning of flank outflow had been 55 hours for 1919, 64 hours for 1916, and 102 hours for 1926.

The maximum daily frequency of earthquakes in the 1926 eruption was on April 15 (86 shocks), the first day of free-flowing flank eruption, but from April 10 to 14 the numbers were almost as great. For the next 15 days they declined from 61 to 0. Intensity of earthquakes increased as frequency diminished. The two large preliminary shocks were located as coming from the whole southwest rift, and it may well be that a general slip occurred, for the summit vent was a step fault, and Hilo reported small tidal waves. The located epicenters showed no progressive increase of distances as in the other eruptions, where a rift had ruptured farther and farther from the recording seismograph. A number of the epicenters were east of Mauna Loa summit, as though the centers were on a fault plane dipping eastward from the crater. Numerous quakes centered on the southwestern Mauna Loa rift in 1924–1925, and a strong one in February 1926 centered on the northeast Mauna Loa rift. The harmonic tremor ended April 22. There was northeasterly tilt at the Kilauea station April 11–24, where it was westerly before and after.

MORE DAYTIME EARTHQUAKES

The daytime seismograms, 8 a.m. to 8 p.m., were compared with the nighttime seismograms 8 p.m. to 8 a.m. The earthquakes were from Mauna Loa fault planes. The 12-hour periods, beginning 8 a.m. April 14, gave the following numbers of shocks during the decline of seismicity for a week:

	Day	*Night*
April 14, 1926	32	24
15	51	32
16	37	29
17	29	16
18	12	8
19	12	8
20	18	2

The average indicated 60 per cent more earthquakes by day than by night, as though the presence of the sun overhead stimulated earthquake frequency.

KILAUEA DURING MAUNA LOA ERUPTION, 1926

In Halemaumau pit there were the usual fume and sulphur stain, and occasional wall slides north. On the day of Mauna Loa outbreak, the Kilauea southwest rift was working, and where it emerges as tunnels in Halemaumau wall there were two large slides. Hydrogen sulphide smell was again perceptible. April 13 rim cracks showed movement south of Halemaumau. Three of the quakes registered on April 20 had Kilauea epicenters. After the Mauna Loa eruption ceased, Kilauea was peaceful. May produced only 44 earthquakes, two of them felt, and the pit showed no other change than a few slides.

BORING FOR TEMPERATURE, KILAUEA

Drilling to determine underground temperature in the surface lava of Kilauea was begun in April 1922 and continued in 1926 and 1927 by a different method. The first object was to determine the thermal gradient in depth, the second to determine differences of temperature at regular intervals across country. The first wells were 5 to 20 meters deep, at the Sulphur Bank near Volcano House, in the Observatory grounds on the northeast rim of Kilauea Crater, and in the floor of the crater (Pl. 2).

At the Sulphur Bank, 400 meters back from the Kilauea rim, the temperature was 95.5° C. in steam which rushed up with purring noise. The temperature was the same to 20 meters depth. The steam contains 0.096 per cent SO_2, 0.004 per cent S, a trace of HCl, and 3.7 per cent of fixed gases, mostly CO_2 and air. It happens that 96° C. is the boiling point of water for the elevation, 1204 meters. No gradient was detected, the steam was evidently rising through fissures dipping toward the crater, which the boring crossed obliquely, and the rock contains iron and copper sulphides. Drilling deeper was financially impracticable in such hot rocks.

At the Observatory grounds, 20 meters back from the Kilauea rim, the bore hole at 3-meter intervals of depth gave 36°, 39°, 37°, 37°, 37°, 36° C. Thus the warmest ground was 6 meters down, and the bottom and the top were cooler.

Under the east-central floor of Kilauea Crater, the temperatures at 3-meter intervals of depth were 35°, 45°, 54°, 58°, 65°, 64°, 69° C. Here a gradient is evident, interrupted at 18 meters, where gravel beds were encountered, possibly 1790 explosive fragments, on a buried promontory of the east wall of the crater.

For the horizontal temperature change, holes 5 cm. in diameter, 3 meters deep, were located 300 meters apart, at the intersections of a surveyed net of equilateral triangles in plan. By March 1927, 29 holes had been drilled east of Halemaumau on the Kilauea floor. At the eastern floor margin, there are steam temperatures with deposit of sulphur and sulphates, where the contact between lava fill and wall permits hot gases to rise from greater depths than elsewhere. This is probably the condition at Sulphur Bank above mentioned, but that is an older wall-crack contact.

It was expected that isothermal lines, *in plan*, would show some geographical relation to Halemaumau pit, but it soon became evident that isothermals would be guided by cracked zones, where the deeper cracks brought up hot gas. The difference between air temperature and bottom temperature of the 3-meter holes ranged from air temperature to 84° C. With air temperatures 21° to 25° C., there were five holes in the crater floor 3 meters deep showing the same temperature at the bottom—that is, no gradient. Three others showed temperature higher than air at the bottom, by only 1° to 1.5°. One day at the bottom of Hole No. 100 it was 27°, the air being 22°; another day 25°, the air being 20°; and another day 24°, the air being 18°. Here apparently the vapors warming the hole fluctuated in temperature with the weather. One hole on two different days gave readings at the bottom of 78° and 90°, while a point about half way down was hotter, and inconsistently so on different days.

These results showed that vapor in cracks, rather than rock conduction, heats the pile of lava flows; that near the surface the temperature does not consistently increase with depth; and, lastly, that the temperature at the same place changes with time. A remeasurement of many of the holes in December 1929 showed rise of temperature 1° to 14° in 1 to 3 years. From all the work, strategic places for measurement of temperature should be found, and these equipped with self-recording apparatus (Haw'n. Volc. Obs'y., Bull., April to December 1922, March 1927; Jaggar, 1924, Monthly Weather Review).

HALEMAUMAU QUIET INTERVAL, 1926-1927

Between the April Mauna Loa outbreak of 1926 and the July Kilauea inflow of 1927, the pit was quiet in outward appearances, though the 44 to 267 seismic disturbances monthly, gave evidence of magmatic motion underground. Thus the curve of monthly frequencies steadily rose to a maximum of 267 in August 1926 and sharply declined after September. Just before the equinox there was systematic weekly rise in frequencies to September 8, with graded decline thereafter. Tilting of the ground at the Observatory, on the northeast rim of Kilauea, changed as usual to north and east after June, or away from Halemaumau, and this continued during the autumn. Slides in the pit increased with earthquake frequency. There were 11 quakes in September originating 40 to 80 miles from Kilauea, suggesting Hualalai as origin.

During the first half of 1927 bright-yellow sulphur was spreading on the south talus of Halemaumau. The monthly number of earthquakes was 45 to 85, of which one or two were felt each month; as before, number of slides appeared to increase with the increase of earthquakes. Tilting was larger when the earthquake frequency was greater. Tilting was mostly west and south until May, west and north thereafter. A large deep equinoxial earthquake felt throughout the Hawaiian islands March 20, 1927, recalled the similar one of just a year before. Some objects in Hilo were overturned by the long swaying ground motion. In June some fresh vaporing cracks opened around the northeast rim of Halemaumau. A singular phenomenon June 8 at 1:30 a.m. was a booming noise, a glow, and a swaying concussion. The latter was not confirmed as a perceptible earthquake by the seismograms. Possibly a meteor fell.

HALEMAUMAU ERUPTION, JULY 1927

This was a quiet outbreak inside Halemaumau pit (Pl. 53), resembling the July event of 1924. It added a new lava floor to the bottom of the pit. Cracks at the east rim widened before the outbreak, and there were avalanches northeast and southwest on the Kilauea rift belt where it intersects the pit walls. The time of outbreak, indicated by continuous harmonic tremor, was 12:32 a.m., July 7. There was a moderate earthquake at 3:21 a.m., indicated as originating 35 miles away.

Four fountains appeared, the three largest 125 feet high, in a southwest-northeast line. This line nearly accorded in direction with the dikes of the rift belt. The southwest fountain built a cone 120 feet up the south-southwest talus slope, just under the 1920 rift tunnels in the Halemaumau wall; it discharged a river of lava 15 to 20 feet wide that flowed down the slope to a lake of lava, covering the debris that lay over the 1924 floor. The next fountain northeast was 600 feet away, near the bottom of the large west talus, 30 feet above the lake, sending down two streams and ejecting spatter; it was nearly over the 1924 cone. Small twin fountains were in a double vent at the lake edge 200 feet farther northeast. Eight hundred feet still farther, near the foot of the north-northeast talus, was the third large fountain, quickly surrounded by the lake, so that its gushings came through the pool. The lake rose rapidly the first hour, slowly thereafter.

After a day the three northern fountains stopped. The southern cone stopped visible flowing July 20. The lake surface rose 80 feet, mostly the first day. The floor area became 30 acres. The south cone stood about 50 feet above the surrounding talus. Probably 50 per cent of the exterior lava of the eruption, by volume, poured out during the first hour. The first day was spectacular, the fountains made thundering noise, sulphurous fume rose from the southwest side, and new filaments of Pele's hair and frothy, brown pumice lumps fell outside the pit. The new lava had maximum dimensions of 1760 feet northeast-southwest, 1420 feet southeast-northwest; the lake edge was 2480 feet above sea level, and the highest southwest cone 2602 feet.

There were 72 local earthquakes for July 1927, fewer than for January or for May, and not exceptional. The harmonic tremor continued until the early morning of July 8. There had been an interval of 17 minutes of tremor the evening of July 6, preceding the eruption by 1½ hours. Intensity of earthquakes increased after July 24, so that there were seven which were perceptible before the month ended. The distances of origin approximated 30 miles, which is not the Halemaumau distance and suggests Mauna Loa. Avalanches also increased. The lake crust had collapsed about 15 feet July 8, and the south side of the floor collapsed farther July 22. The large southern cone began to be battered by slides soon after the eruption. Sulphur spots appeared, and the odor of spicy sulphur was noticed.

HALEMAUMAU QUIET INTERVAL, 1927-1928

The last 5 months of 1927 constituted a short repose period, within a series of such intervals destined to average about 13 months between beginnings of 11 eruptions of the Hawaii volcanic system (Kilauea and Mauna Loa) for the 11.3 years following the 1924 crisis. These intervals were approximately as follows, but due allowance should be made for several weeks of action in the later eruptions, so that these intervals are not all repose:

1924 July to 1926 April	**20 months**
1926 April to 1927 July	**14 months**
1927 July to 1928 January	**5 months**
1928 January to 1929 February	**13 months**

1929 February to 1929 July	5 months
1929 July to 1930 November	16 months
1930 December to 1931 December	12 months
1932 January to 1933 December	23 months
1933 December to 1934 September	9 months
1934 September to 1935 November	15 months

The April 1926, December 1933, and November 1935 events were Mauna Loa; the others were Halemaumau. There is marked alternation of long and short intervals, and a tendency to shortest intervals in the middle of the decade. Actual repose periods averaged close to a solar year.

The seismic character of this 5 months period of 1927 was peculiar in that it led up to a high frequency of 243 local shocks in December, 5 of them perceptible, and a spasm of volcanic tremors between December 3 and 5. The distances of origin indicated for the December earthquakes were, in much larger number, 14 to 36 miles corresponding to Mauna Loa rifts rather than in the shorter range corresponding to Kilauea. There were the usual avalanches throughout the autumn, and these increased in number in December. They were not particularly localized but wandered to the different walls of the pit. The monthly numbers of seismic shocks, mostly very feeble, from August to January inclusive, were 75, 103, 76, 191, 243, 149. The cluster at the December solstice is unmistakable, and this led to an unusual type of Halemaumau outbreak in January.

LANDSLIP ERUPTION, JANUARY 1928

The event that constituted a very small outbreak of fiery lava in the bottom of Halemaumau pit occurred, as in so many cases, just after midnight. It came at 12:26 a.m., January 11, 1928. There had been western slides, and a big avalanche at this time overburdened the northwest talus cone and converted it into a landslip that covered 5 acres of the lava floor. There was a prolonged roar. Brilliant red glow appeared in the pit and disappeared in 20 minutes. This was from gushing lava up cracks in the floor about the edges of the landslip.

Slides continued on all sides of the pit. Dust stain had been belched over the floor ahead of the landslip. Glowing lava, flowing sluggishly and cooling, made a crescent 500 feet long, from two vents at the south side, and one at the east side, of the sunken crust of the hardened northwest lava pool of July 1927. Another vent was making a fiery pot emitting blue flame at the north cone site of 1927. The lava of the main streams was of the "shark skin" type, very rough pahoehoe. The edge of Halemaumau north-northwest had fallen and carried with it a survey station. The northwest talus conoid was completely stripped, revealing a rock slope below. A few tremors registered on the seismographs appeared to be effects, not causes, of the landslip and preceding avalanches. No hissing was heard. No harmonic tremor appeared such as ordinarily accompanies eruptions.

The explanation adopted at the time was that the shifted weight of the landslip squeezed up 1927 lava, still liquid beneath the floor. This, however, did not account for the sequence of both landslip and eruption after the large seismic frequency which had begun in November, 583 shocks in 3 months, and no shock at the moment of the slide. It was just as likely that tilt or lift of the floor plug, magmatically disturbed from below, ruptured forth a lava emission and at the same time released the landslip.

This explanation is correct, for just a year later another landslip, on the opposite side of the pit, was followed in a month by an eruption; this involved a prolonged heavy breakage of the whole rim of the pit southeast, without any seismic crisis, and with every indication of a subterranean magmatic crisis. This magma obtained release of its gas in a highly effervescent eruption, not timed by the incidence of the landslip. In view of the heaving of the lower west wall slab in its entirety in the later 1934 eruption, with the lift of bottom plug, and lava squirting from behind it up vertical west fissures concentric with the pit, this 1928 west avalanche with lava was probably a premonitory similar wall-crack uplift.

These sequences appear to mean that (1) a pronounced seismic crisis is of magmatic origin in Hawaii, (2) emission of lava in a crateral pit is a cumulative certainty not stimulated by superficial slides or small shift of weights; and (3) the irresistible intrusion of such lava may disturb the plug and the pit walls as a local phenomenon, while a seismic crisis is a more widespread affair, which may or may not correlate with the local eruption by any close correspondence in time and place.

EARTHQUAKE FREQUENCY 1928–1929

The 13 months of quiet that followed the landslip eruption had a striking decline in monthly frequency of earthquakes, from 165 in February 1928 to only 37 in February 1929, and this in spite of the fact that February 1929 produced another outbreak of Halemaumau lava. The 6 months that culminated in the January crisis from September 1927 to February 1928 inclusive produced 1827 local shocks; the following 6 months produced only 451.

The distribution of intensity of quaking showed nothing remarkable; each month ordinarily had from one to five shocks that could be felt, the larger number merely seismographic.

Distance of origin from Kilauea rarely exceeded 30 miles, and within that range there was great variety of measurements. Thus in February 1928 the seismograms indicated distances (not in orderly sequence) of 1, 2, 8, 11, 12, 25, 28, and 40 miles, and in later months the gaps in this list could be filled with distances of 14, 15, 16, 19, 20, 22, 30, and 33 miles.

The lack of any constant or repeated distance of origin, as interpreted from the difference in time of arrival of preliminary and secondary waves (and remembering that depth is also involved), suggests an endless shifting of loci of intrusion under Mauna Loa and Kilauea. An exceptional earthquake in April indicated origin 53 miles away, and a seismogram in January 1929 measured 98 to 115 miles from Kilauea station.

MEANING OF HAWAIIAN EARTHQUAKES

It has become increasingly evident from earthquakes, measured seismographically on Hawaii, that large felt motions are often deep and perceived about equally all over the island. The notion of a localized epicenter feeling shocks more strongly may apply to large districts, but not to small ones. The evidence accumulates that two main applications of magmatic stress shake the island: one is dike intrusion tensionally stressing the rift belts; the other is outflow, that somewhere depletes a dike or a gas foam and causes graben collapse. Many small shakings characterize ordinary times of lava pressure. Fewer and stronger shocks go with gravitative release at the end of a flow period.

There is an increasing collection of records to show one or more strong shocks, of deep origin and not localized at the crater, which precede or accompany a crateral eruption. These island-shaking shocks, preceding an outbreak of either Kilauea or Mauna Loa by several weeks or months, are problematical. They probably represent the release of magma from a lower to a higher level within the center of the active system and so bring collapse to the region evacuated and tension on the fissure invaded. The former is larger, the latter small. Hence areally the collapse earthquake is a large event, while the fissure trembling is local and nearer the surface.

HALEMAUMAU REPOSE, 1928–1929

There was a big northern avalanche in Halemaumau February 20, 1928; other avalanches the same month were at the southwest, and pieces of the upper edge fell off on the north and northeast. A moderate earthquake, strongly felt, centered at Kilauea February 26 accompanied by southerly tilt at the Observatory of more than 2 seconds. This was a month of even more seismic activity than January and ended the exceptional seismic spasm.

The eastern rim was falling away, and the 14-ton boulder of 1924 was now close to the edge. Slides continued in March but dwindled during spring and summer.

The Observatory was now measuring cracks on the Halemaumau rim as a new routine; the cracks are marked with copper studs on opposite sides, and a steel tape is stretched between them reading to half-millimeters. This measurement was stimulated by the January rim changes and by the expectation that the widening rim-chasm holding the 14-ton boulder would soon give way. The eastern cracks opened several inches.

Another item of routine started by Engineer R. M. Wilson is the measurement by leveling of the relation in elevation of Halemaumau rim to the datum bench mark "Spit" on the gravel ridge in the south end of Kilauea Crater. Differential movement of large fractions of a foot has occurred, and readings with precision transit of horizontal angles from the Observatory, across Kilauea Crater, and across Halemaumau pit are yielding results of importance for comparison with the leveling and with trigonometric surveys made in 1921 and 1926 (Wilson, 1935). In July 1928 (Pl. 54) a new carefully made map of Halemaumau (Pl. 82c) was produced by Mr. Wilson, and in September a one-component seismograph was set up in a hut on the southeast rim of Halemaumau.

Large slides in the pit were renewed the last half of August 1928, as though the plug were lowering. Part of the north rim fell in. Light avalanches the last half of October were followed by slides in November from the north rim and some highly localized Kilauea earthquakes, five of which were felt. On November 24 there were 20 small shocks in 26 minutes. December 24 there was an earthquake accompanied by north tilt, and excessive tilts to the north and northeast. The earthquakes still appeared local to Kilauea.

RIM CRISIS AT HALEMAUMAU ,1929

Avalanching at the southeast rim of Halemaumau, where the road terminus touches the pit, is unusual. Accompanied by much tremor and widening of rim cracks, such sliding was continuous January 5 to 10, 1929. On January 8 a crack 11 feet from the edge, at the tourist stand, had opened 1.2 feet in 35 days. This crack by January 18 had widened 2 feet more.

Such was the crisis, and the situation recalled the landslip of a year before. On January 7 a big avalanche and landslip occurred again, but on the side opposite the 1928 slide. This time it was on the south talus, the fall of rock was mostly from halfway down the wall, the surveying station on the rim fell in, the landslide debris spread halfway across the floor of Halemaumau, and the slides thereafter spread to the southeast and to the upper rim. With a culminating crash on January 10, 100 longitudinal feet of the east rim at the tourist stand fell. The National Park authorities took steps to move the lookout platform farther north. The whole rim at the old location was shattered and crossed by wide new chasms parallel to the edge of the pit.

January 1929 produced no seismic abnormality. There were 57 minor shocks, one of them felt, and those few which indicated distance of origin on the seismograms pointed to Mauna Loa distances or farther.

HALEMAUMAU OUTBREAK, FEBRUARY 1929

February produced only 37 shocks, but there was one tremor spell for 11 hours which was accompanied by a lava outbreak on February 20. Otherwise the seismicity was like that of January, except for a strongish quake, centering under Kilauea, February 5 at 2:25 a.m., and accompanied by east-northeast tilt at the Observatory. It was felt all over Hawaii. This shock was probably premonitory.

The outbreak lasted a day and a half only but was of remarkable interest because of its effect on the seismograph near the southeast edge of Halemaumau. This seismograph registered tilting away from the center 2 hours before the eruption, accompanied by 14 small earthquakes. The outbreak was at 12:46 a.m., February 20, when continuous harmonic tremor appeared. This was strong during the lava fountaining, all lava motion ending at 1:15 p.m., February 21. At the end of the eruption for 5 hours the southeast ground under the seismograph tilted back toward the pit.

As in so many cases the eruption was just after midnight, along a fracture in a straight line along the northwestern side of the bottom lava floor of Halemaumau. It was on the side away from the January landslip. As the landslides had made the bottom cup smaller, so the new lava lake was smaller than that of 1927, measuring only 1600 feet in diameter and 45 feet deep. There was a line of fountains, with a big one at the north end. This was of the Mauna Loa type shooting up frothy lava 200 feet and making a streaming with bright-line pattern out into the lake. There was a steady roar, blue fume arose, while basaltic pumice and glassy needles fell outside the pit. There was almost no avalanching. The large fountain built up a pumice-and-lava heap from which cascades poured down, and this broke down to an "arm-chair niche" at the end. The usual rampart formed about the lake edge.

The rim tilt was 11 seconds away from the center between 9:15 a.m. February 19 and 12:45 a.m. February 20 (the time of outbreak). During the activity tilting mostly ceased. The southeast rim region tilted back toward the center 6 seconds, largely between 8 a.m. and 1 p.m. on February 21, or while the lava was going down. There was a net gain of 5 seconds of tilt away from the pit, indicating tumescence accompanying lava inflow. This 1929 measurement led to establishment of perimetral tilt cellars with special instruments in 1932. The radial centrifugal tilt for 15 hours February 19 was definitely premonitory, and the centripetal tilting back for 5 hours gave evidence in advance of the approach of the end. (Compare long-term tilting, Part 3, Pl. 87.) After February 21 the central lake lowered 15 to 20 feet, the last trickling lava welled up between crusts, yellow stains developed at the pumice "throne" where the fountain had been, and there was the usual increase in intensity of seismic motion, with two felt earthquakes on February 21 and one on February 24.

FOUR MONTHS LULL, 1929

March produced 57 local earthquakes, numerous spells of tremor, seismic origins 2 to 30 miles away, and minor slides at Halemaumau. April was very quiet, with sulphur staining the Halemaumau floor; there were 33 shocks, and the tremor lessened. May was commonplace, with 28 shocks and northwestern slides that sent debris over the new floor. June showed a change from southerly to northerly tilt at the Observatory, there were 38 earthquakes, two of them dislodging slides in Halemaumau on June 18, the second shock felt strongly in Kau (south district), Puna (east district), and Hilo. July was not remarkable until lava erupted in Halemaumau on July 25.

LAVA ERUPTION HALEMAUMAU, JULY 1929

At 4:35 a.m., July 25, along with a series of six very feeble earthquakes and easterly tilt at the Observatory, liquid lava burst up (Pl. 55a) through the talus along a fracture tangential to bottom plug on its west side. This eruption lasted 3 days, instead of 1½ as in February. The big fountains were at the base of the large west slide-rock conoid.

The tilt phenomena at the Halemaumau seismograph southeast differed from that of February. There was inward tilt the first day of activity, toward the pit center, followed by outward tilt. Again tremor was registered continuously while the lava fountains were in action. The eruption ceased about midnight July 28.

The lava fountains were continous spraying jets, flinging up brown basaltic pumice, making a spatter bank against the debris slope, and sending a flood over the botto greatly enlarging the floor area. The first day produced 44 feet of fill; this had increased the second day to 77 feet and the third day to 94 feet, but shrinkage and backflow at the end lowered this by 30 feet. About 97 million cubic feet of lava came in during 85 hours, and the middle of the new floor was left 1050 feet below the rim. There were glow cracks at the end of July, but the eruption stopped abruptly, and the new layer of lava cooled quickly.

The number of local earthquakes in July was 91, double the figure for the preceding months, mostly very feeble except for three that were felt. Most of the shocks were during the weeks before the eruption. East tilt accompanied three of the very feeble shocks after the eruption. Thirty disturbances occurred the first week in August, and two of these were felt.

AUGUST-SEPTEMBER INTERVAL, 1929

There were 53 days between the July eruption of Halemaumau and an extreme seismic crisis on Hualalai. August produced about 100 earthquakes and a few Halemaumau slides. There was slumping about the July conduit, leaving a terraced fault bank and 20 hummocks. Until September 19, the month was extraordinarily quiet, with only four trivial earth shocks in the second week. Then came the transition, from 9 shocks the third week to 221 the fourth.

HUALALAI EARTHQUAKES, 1929

From the evidence afforded by distance and location of epicenters, this event September to November 1929, which involved thousands of earthquakes damaging North Kona and Kohala (west and north) districts on the island Hawaii, marked an underground shift of magma from pressures affecting seismically the Mauna Loa south rift to new pressures upsetting the equilibrium of Hualalai and Puu Waawaa. The episode resembled the sudden shift in 1868, from activities of the Mauna Loa north rift to the south rift. At that time thousands of damaging earthquakes developed near Pahala, Hilea, and Kahuku, and the south rifts of both Mauna Loa and Kilauea broke into eruption. In the present case no visible eruption ensued.

Suddenly small earthquakes began to be felt September 19 near Hualalai volcano. Puu Waawaa, a large cone north of Hualalai, became nearly the center of maximum motion. The people of Puu Waawaa ranch had thought their countryside nonseismic. Large destructive earthquakes about grade VIII Rossi-Forel occurred September 25 and October 5. In Kona 6211 earthquakes were registered between September 21 and October 16. No lives were lost, but damage was done. Houses, roads, stone fences, dirt fills, tanks, and masonry were broken by incessant rocking from the direction of the mountains toward the sea. Hualalai had been in lava eruption in 1801, and a flow was now looked for, but none came. The strongest motion and greatest destruction was in Puu Waawaa ranch. The highest earthquake frequency was on the southwest slope of Hualalai at Honokahau. Only there was rumbling heard. The populace slept in tents and motor cars. At times the windows rattled continuously for hours. Puu Waawaa, with a shock recorder of magnification ×25 registered an average of 10 shocks per hour for 26 days, nine times as many as were recorded at Kilauea on seismographs of magnification ×120. Maxima of frequency clustered about the dates of the major earthquakes. There was much higher frequency about the September 25 maximum of intensity than about the two later times of very strong earthquakes, October 5 and October 8. The damage to water tanks and masonry extended to Waikii on the high west side of Mauna Kea and to Waimea farther north. The decline in numbers and intensity was steady after October 9, but the aftershocks located in Kona continued until the end of the year.

Two characteristics of this earthquake swarm differed from the usual phenomena of a large earthquake. Generally the great shock comes first and is followed by decline. This series waxed and waned past three maxima with a long series of hard jolts. In this it resembled the volcano-seismic crisis of Montserrat 1933-1935 (Volcano Letter No. 449, 1937; MacGregor, 1938; Powell, 1938; Perret, 1939). The second feature was the great amplitude of the minor preliminary tremor indicating distance of origin on the three seismographs Hilo, Kilauea, and Kealakekua for the big earthquakes of September 25 and October 5. The pens were almost immediately flung off the drums, though they are 40, 30, and 60 miles apart and are similar distances from the supposed epicenters. The longitudinal preliminary wave motion of small amplitude and quick period was well marked in smaller shocks. These big shocks made characteristic preliminary phase seismograms at Honolulu 200 miles away. The explanation must be that the first movement of the P-phase itself had extraordinary energy or else that a mass displacement of the island was the first jolt.

INTERVAL OCTOBER 1929 TO NOVEMBER 1930

This was a dormant time for lava activity. The July lava of 1929 in Halemaumau pit of Kilauea had left the scar of its big western fountain in a built-up heap surrounded by basaltic pumice and shaped like an armchair. What had been the lava lake was a lumpy floor 1050 feet below the rim, surrounded by a rampart. Changes the last half of 1929 were the overlapping of debris heaps, from earthquake slides mostly, upon the edges of the lava floor. By December both earthquake frequency and avalanching were remarkably slight, and at the end of the year part of the pumice cone of July had collapsed.

METHODS AT KILAUEA OBSERVATORY, 1929

When spells of general sliding at the Halemaumau wall occur, rim cracks widen, even on the side remote from the avalanches. These phenomena were studied by occasional measurement with steel tape and calipers (Volcano Letter No. 283) at marked cracks, and avalanches accompanied uplift of the rock structure, just prior to outbreak of lava in the pit January 11, 1928. Cracks opened, with southern avalanches, in January 1929 preceding the eruption of February, and tilt away suggested swelling. All rim cracks during 3 years tended to open, 10 out of 15 caved in over the pit rim, became dangerous as wide chasms, or broke down their markers by collapsing. The caving in of rim slices between crack and pit was enlarging Halemaumau. The cracks opened gradually and widened as chasms became larger at points nearer the pit edge, where the cracks emerge tangentially. The wider the crack, the more it opened. Big avalanching spells between 1927 and 1930 progressed to Halemaumau walls east, south-southwest, northwest, south, and north-northwest. These places are notably not northeast and southwest, where the steepest walls are, and where the deep rift goes through. They are rather at the emergence gulches, where concentric cracks behind buttresses open into the pit as chasms. These cracks are subparallel to the rift system and lie back of the two flatter pit slopes northwest and southeast. The crumbling that breaks down these inward-sloping and longer walls tends to make the pit a circle by rounding out an elongated pentagon, but always the two end walls, cemented by vertical rift dikes, remain the most nearly upright.

The measurement of tilting of the ground at the Observatory on the northeast rim of the greater crater Kilauea (Jaggar, 1920; Jaggar, Finch, and Emerson, 1924; Jaggar and Finch, 1929; Volcano Letters Nos. 276, 349, 467) has been improved and becomes a subject of special interest because of the instantaneous response of the seismograph in the Halemaumau hut to approaching eruption. That instrument shows much greater tilting than the ones on the northeast rim of Kilauea Crater. It was now planned to place three clinoscopes (picture, Volcano Letter No. 437) around the circle of the pit to see if the tilting is quaquaversal.

Systematic plotting of the tilts at the Observatory northeast of the greater crater for 15 years showed an agreement in 1918 with the idea of tumescence at the climax of the overflowing part of the cycle. The depression crisis of 1924 produced inward tilting of similar large amount (Pl. 87). The discussion of this (Part 3) cannot here be extended, but the tilting proves that Wilson's "first thought" level difference of about 3 feet elevation of Volcano House between 1912 and 1921 was correct (Wilson, 1935, p. 47). The large centrifugal tilt of 1918 was an accurate offset to the centripetal tilt of 1924 at the Observatory, which is a few feet from the Volcano House bench mark of the leveling. Therefore the doubt about rod length error may be disregarded from the volcanologic evidence. Kilauea pit was swelling and overflowing in 1918: it collapsed inward in 1924. Tumefaction, tilt, and leveling agree that the mountain top rose.

There is also good evidence of eastward tilting coincident with the more distant events of Mauna Loa to the west, and there are tilt earthquakes, leaving seismograph pens instantaneously displaced, in the sense of tilting of the fault block on which the seismograph chamber is built. This is not release of instrument friction, for several instruments show it simultaneously.

HALEMAUMAU IN 1930

For 11 months the year 1930 was without any unusual seismic or volcanic events. Moderate and slight felt earthquakes and avalanches occurred in September and October. Otherwise the report of each week until the autumn was notable in showing remarkably little of interest, and the frequency of earthquakes declining.

Near the east edge of Halemaumau a 14-ton boulder had fallen in 1924 into a wide chasm trending parallel with the margin of the pit. Earthquakes and the undermining effect of avalanches would inevitably wreck the slice of rock between boulder and pit, for the boulder acted as a wedge downward when earthquakes swayed the rocky slab on the pit side of it. It is easier for any rim crack to open for this reason; if it closes, the tectonic mass pressure must crush enclosed fragments.

On September 10, 1930, about 9:30 p.m., a succession of 14 slides started, enlarging during the night and registering on the pit seismograph. So recorded, but unseen, the 14-ton boulder finished its career in talus fragments, carrying with it a segment of the east rim 50 feet long and 30 feet wide, making an estimated fall of 65,000 tons of rock, and extending the pit diameter at that point. Beginning September 14 adjacent rim rock fell from time to time for 4 days, carrying away a 100-foot segment 50 feet wide. The wedge rhythm started by the big boulder in the crack had propagated.

TEMPERATURE OF STEAMING CRACKS

About May 1930 the recording of temperature of a narrow steam crack 100 yards south of Halemaumau was begun, and with it records were made of air temperature, rainfall, and other meteorological conditions. For 4 months, the temperature of the crack remained remarkably constant, about 70° C, and no influence of weather conditions was detected. In September two more cracks were studied by daily thermometric readings, one close to the south rim of Halemaumau, and one on the northeast Kilauea rim. This procedure is in continuation of measurements started in 1912 and augmented by making bore holes from 1922 to 1927. Temperatures vary from that of the air to 320° C, but the only response to coming eruption is that freshly opened cracks emit sulphurous fume close to the active pit, and become red hot preparatory to ejecting lava. The vapor cracks like the Sulphur Bank at 96° C or lower, even when they contain sulphur and deposit alum, show no change that has yet been discovered accordant with lava emission or eruption, but readings at two different epochs in the bore-hole series showed some general rise of temperature between 1926 and 1929.

PRELIMINARIES OF 1930 ERUPTION

Moderate and slight felt earthquakes and avalanches in September and October 1930 led to a new lava eruption in the bottom of Halemaumau pit on November 19. On October 20 there was a moderate earthquake accompanied by a sudden northerly tilt at the Observatory. This shock was felt over the entire island but appeared to center under Kilauea and led to the publication October 23 of the suggestion that it was "the forerunner of the appearance of lava in Halemaumau." Increase of earthquakes and tremors the week preceding November 16 and marked tilting of the Kilauea rim away from Halemaumau led to the report of increase of pressure and movement of lava under Kilauea. The rim of Halemaumau pit itself was tilted upward and outward 5 seconds during the 6 days preceding eruption, and 5 seconds more during 1.52 hours immediately before the gush of lava described below. When the fountain gas escaped, the pit rim tilted back through 7.5 seconds during 18 hours. Continuous tremor was very strong for 3 hours, then moderated and continued throughout the eruption. All this is comparable to February 1929.

HALEMAUMAU INFLOW, 1930

At 1:29 p.m., November 19, the floor of Halemaumau started to swell rapidly under a spot 100 yards in front of the cone remnants of 1929 at the base of the west talus; huge blocks of the old crust were thrown into the air by the first gush of fountaining lava. Numerous fountains developed along the southern edge of the 1929 floor, and the progress of the lava across the floor was by spreading of flows which concentrated into a pool surrounded by ramparts and took some days to cover the former floor of the pit. Overflow of this inner saucer on three sides through the border rampart drained the new lava, and the streams finally reached the base of the Halemaumau walls. After 2 weeks of action the remaining lake area measured 500 by 800 feet, the cone opposite the south talus was 75 feet high and 200 feet in diameter at the base, and the lake lay at the top of a new mound sloping away to an elliptical border measuring 2300 by 1700 feet. The depth of the structure above the former bottom was 175 feet at the cone, 100 feet at the lake fed by the cone, and about 50 feet deep at the north side of the floor. The eruption ended December 7 (Pl. 55b); tremor ended at the same time. Though this eruption was longer than the 1929 outbreaks, the gradual spreading over the bottom implied less violent foaming gas pressure than in most current eruptions. The first fountains were only 50 feet high.

YEAR 1931 STATISTICS

It may be useful to summarize statistics of seismic motion and ground tilt for the type quiet year, 1931, between two Halemaumau eruptions. The eruptions began November 19, 1930, and December 23, 1931, and lasted respectively 18 and 13 days.

The months produced the following phenomena at the Observatory on the northeast rim of Kilauea Crater:

December 1930: Halemaumau since 1924 had increased the dimensions of its bottom from 1000 by 700 feet to 2200 by 1700 feet; the elevation above sea level of its bottom from 2360 feet to 2650 feet; six eruptions in 7 years totaled 46 days of inflow; the volume of new lava was 463 million cubic feet. The week ending December 28, 1930, had 43 local seismic disturbances largely tremors, and Halemaumau pit showed blue fume and outward tilt of its margin. The habit of the seismometric frequency was 3 to 5 earthquakes per week, and 25 to 40 tremors. Five weeks' tilts in December of 1 to 2 seconds were NE, NNE, NNE, NE, W at Observatory.

January 1931: Four weeks frequency 58, 28, 29, 44 disturbances; and tilts about 1 second per week were S, WNW, WSW, E; SW is toward Halemaumau, NE is away from it.

February: Four weeks frequency 67, 14, 14, 19; tilts 0.36″ to 1.74″; ESE, WNW, SSW, SSW.

March: Five weeks frequency 28, 19, 37, 25, 33; tilts 1 to 2 inches; SSW, SW, S, SSW, E. Note the contrast to December.

This is the semiannual habit of tilt on the northeast rim of Kilauea greater crater—southwest in spring, northeast in autumn. The northeast tilt away from the Halemaumau center has frequently led to eruption or eruptive increase. The sharp reaction west at the end of December is probably reversal of tumescence after the eruption. This was the solstice month. The reaction east at the end of March is probably the first pulsation of return of tumescence after equinox. It should be noted that east is the direction away from the greater eruption center Mauna Loa. The significance of the sun being farthest north and its crossing of the equator may be tidal stress on the crust in the volcanic belts of the equatorial annulus of extra mass.

April: Four weeks frequency 61, 17, 26, 27; tilts 1″ to 2″; W, W, SW, SSW.

May: Four weeks frequency 38, 29, 26, 34; tilts 1″ to 0.8″ in the last week; E, SW, SSW, SSW.

June: Four weeks frequency 31, 35, 28, 22; tilts about 1″; W, NE, ENE, NNW.

July: Five weeks frequency 36, 23, 21, 18; tilts 0.4″ to 0.9″; W, NW, NNE, NNE, WNW.

August: Four weeks frequency 45, 29, 26, 23; tilts about 1″; NE, W, NNE, WSW˙

September: Four weeks frequency 42, 60, 46, 30; tilts 0.5″ to 1.7″; SW, NE, E, ENE.

October: Five weeks frequency 22, 36, 42, 12, 45; tilts 0.1″ to 1.9″; N, W, NNE, N, SSW. Northerly and easterly tilts replace the southerly and westerly tilts of April and May, and the angular amount is increasing.

November: Four weeks frequency 59, 87, 53, 24, including both weekly and monthly maxima for the year; tilts also increasing, 0.7″ to 2.3″; easterly greatly dominant, NE, ESE, ENE, SE.

December: Four weeks frequency 27, 57, 34, 21; tilts 0.8″ to 3.2″; ENE, NE, NE, WNW. Outbreak and continuous tremor, Halemaumau, December 23 to January 5.

The maxima begin about the first week in each month, the intervals between maxima averaging 31 days, which is closer to the calendar, or mean solar-rotation, month than to the lunar month. Later in the year the maxima lag past the first week. July, midway between the two eruptions, shows the lowest weekly frequencies; November, the month before the December eruption, shows the highest. December after the eruption began showed continous tremor difficult to evaluate on frequency basis. Observation showed increase of avalanches, fume, and sulphur spots within Halemaumau after mid-year.

If we take directions of tilt shown, as summations of those weeks per month containing north and east, and those containing south and west (NE being away from the center), we get from December to December.

	D	J	F	M	A	M	J	J	A	S	O	N	D
N + E..........................	8	3	2	1	0	1	5	6	4	5	4	5	7
S + W..........................	0	5	6	7	5	6	2	3	3	2	3	2	1

Thus December 1930 had four north weeks and four east weeks, total 8; April 1931 had no north weeks and no east weeks, total 0.

Inward or downward tilts increase in spring, and outward or upward ones in autumn. The angular amounts increased with approach to the eruption at the end of the year. There was also increase of angular amount with approach to June solstice, and lower values before and after.

OUTBREAK OF HALEMAUMAU PIT DECEMBER 23, 1931

The average of Kilauea outbreaks had been one a year since 1924 so that a new eruption was expectable about a year after the outbreak of November 1930. The tilt instrument at the edge of Halemaumau had shown tilt away from the center of the pit, and the one at the Observatory had shown tilt away from the greater crater. A rim block fell into Halemaumau December 7, there were numerous seismic disturbances the second week of the month, and a smart local earthquake the forenoon of December 23 touched off many avalanches in Halemaumau and on the west wall of Kilauea Crater. That this was the actual pushing up and rending asunder of the inner heap was proved by the immediate widening of measured cracks around the edge of Halemaumau concentric with that edge. Small slides in the pit were continuous.

A distinctive feature of this eruption (2:40 p.m., December 23) was its observation at the moment of lava outbreak by the Observatory engineer, E. G. Wingate. Working at a surveying station, he heard a rumble, saw heavy fume clouds, ran to the edge and saw the whole floor cracking along a straight line athwart its middle beginning at the southwest, where lava fountains spurted up and spread along the crack. The break occupied half a minute, and just at this time strong harmonic tremor developed at the Observatory seismographs. The bottom crust appeared to be pulled apart rather than to be heaved up and broken. Light-brown basaltic spatter was blown high over the rim wall, and 17 large fountains along the crack had the two highest jets at its northeast end. The blue sulphurous fume welled over the edge and gassed the observer who ran to his car and escaped. Tilt at the Observatory changed suddenly from northeast to south. During the next 11 hours lava foamed into the pit at the rate of 6500 cubic feet per second, and the density of the fume cloud was very unusual for Kilauea. The enormous fountains ceased action early the next morning, leaving a belt of several central gushers and a large grotto fountain at the southwest end of the line.

After this the fountaining first developed numbers of jets, then individual jets at the southwest grotto that were very high, building a huge spatter crescent while the central fountains made detonating puffs at blue fume. By the New Year the fill was 110 feet deep, and the southwestern grotto had piled up a horseshoe cone with its topmost spatter only 650 feet below the rim of the pit. This cone was at the top of a new mound from which flows radiated and developed a lake at the top of the mound. This was a more voluminous fill than in any outbreak since 1924. A phenomenon conspicuous in the eruption of 1934 was that the entire new lava heap, 122 feet higher at the south than at the north, caused some swelling up on the northern side of the bottom area. On January 5, 1932, the three streams from the cones stopped, there were booming noises, and by evening tremor ceased at the seismographs, and only glowing cracks remained in the pit. Thereafter the lake at the top of the heap slumped, left hummocks, and the shrinkage produced small slides from the walls.

The surveys showed a thickness of fill above the 1930 floor varying from 73 to 134 feet. The average elevation of the bottom of Halemaumau was 2789 feet above sea level, or 855 feet below the viewing station southeast. The volume of new lava was 13 million cubic yards.

REVIEW OF HALEMAUMAU INFLOWS, 1924-1931

Seven layers of lava were added to the bottom in 7 years and had the following characters: a typical eruption is heralded by earthquakes, and cracks on the rim of the pit exhibit distension of the edifice by spreading open and so loosening the inside walls as to make avalanches. This is likely to accompany tilt away from center just before eruption. All the eruptions were influenced by the northeast-southwest rift belt which crosses Kilauea Crater; the final gushing either splits the inner floor or wedges its way up along the edges of the floor and in a short time concentrates the inflowing at one vent. There is temporary inward tilting and continuous tremor while the gas escape of the fountains is going on. The whole series of eruptions suggest accumulating upward pressure. As they progressed through the cycle they increased in volume of output and violence of effervescence, with the last two outbreaks the most enduring. The duration of the others was variable from 1 hour to 18 days.

HALEMAUMAU SEISMICITY, 1931

Besides the expectable interval of about a year, evidence forecasting the 1931 eruption included accumulated tilt away from Halemaumau center suggesting upward pressure, and there were excessive tremors and earthquakes 10 days before the outburst, and opening of measured cracks by unusual amounts leading to a rim-block avalanche December 7. A strongish earthquake December 13 was accompanied by rumbling noises and slabs falling down cracks along the Kau Desert rift southwest of Kilauea, and a strong shock at the crater end of this same rift occurred on the forenoon of the day the eruption began (Jones, 1935c).

Features accompanying the eruption were steady tremor which started and ceased in coincidence with lava inflow, the latter dated 1 year and 34 days after the outbreak of 1930; change of tilt at the Kilauea edge from outward to inward as soon as the gas and lava released the upward pressure; the gushing up along a straight crack over the rift line itself; the concentration to a cone built at the Halemaumau wall, at one end of this crack; the accumulation of 115 feet of liquid fill, and a duration of only 13 days.

The seismologist has plotted for the years a curve compounded of the number and intensity of earthquakes and tremors to exhibit seismicity. It is based on Rossi-Forel intensity so that 4 minutes of tremor or two very feeble shocks equal one earthquake of Rossi-Forel Grade I. Owing to the large number of small tremors the curve of seismicity through the four years 1928–1932 oscillates around a weekly figure of about 8 with a trend downward almost to zero in July 1930 and up to about 10 in December 1931.

This curve is punctuated by high peaks at each Halemaumau inflow where the seismicity per eruption rose in a consistently increasing curve through the four eruptions of February and July 1929, November 1930, and December 1931 when the figure for seismicity exceeded 2500. The duration of the seismic spasms also tended to increase, and each seismic peak on the curve is symmetrical. That means a flurry of earthquakes during the eruption, rising above low value before and after. This is an entirely different type of curve from that which accompanied the Hualalai earthquakes of September–December 1929, when there was a sudden burst of quaking of high intensity, followed by a systematic decay curve for 3 months.

LAVA SHRINKAGE, 1932

The spring of 1932 showed phenomena of shrinkage of the floor crust of Halemaumau with increasing avalanches from the walls of the pit during February. Surveys showed that the greatest amount of vertical shrinking in the new lava floor was about 45 feet in the southern part of the pit, where the lava now stood 30 feet above the top of the former 1930 cone, whereas when it was liquid on January 5 the depth above the old cone was estimated as over 70 feet. The edges of the floor remained stationary where frozen to the pit walls, but the average shrinkage downward out in the middle was between 10 and 20 feet. The average depth of fill was about 110 feet.

On March 5 there was a notable collapse of the northeastern wall of the pit, preceded by widening of the measured concentric rim cracks, which were the subject of increasing attention at the Observatory. Several of these cracks were demolished by the caving back of the rim, there was a spasm of many earthquakes, and at night two of the crust fissures at the edge of the new lava floor of Halemaumau showed distinct glow, as though the seismic stress had warped open the thick shell over the still hot January lava.

INWARD TILTING FOLLOWING ERUPTIONS

At the Observatory on the northeast rim of the greater Kilauea Crater, the accumulation of tilt from January 1 to March 28 was approximately 18 seconds south, or inward in the direction of Halemaumau. This is greater southerly tilting than whole years have usually produced, with the exception of 1924, and suggests an intense reaction to the shrinkage, affecting the whole mountain top.

1932 A QUIET YEAR

The remainder of 1932 showed diminishing shrinkage, many more tremors at the pit than appear at the Observatory seismographs, larger tilts at the southeastern pit station near Halemaumau than at the Observatory, and the development of a yellow sulphur patch at the edge of the floor of Halemaumau west. There was the usual waxing and waning of earthquakes and tremors, and the opening of more cracks close to the pit edge whereby avalanches, touched off by earthquakes, occasionally undermined them. Seismicity was moderate. At the summit crater of Mauna Loa in August there was blue fume about the central cones of Mokuaweoweo and much steam along the upper part of the northeast rift.

EXPLORATION OF HALEMAUMAU BOTTOM

Rikan Konishi, a rigger and contractor of Hilo, descended June 12, 1932, to the bottom of Halemaumau to recover two dead bodies resulting from a local tragedy. With 50 helpers and numerous tractors he spanned the east arc of the pit circle with cable and trolley and was lowered in a wooden cage which was bound with iron. This was the only descent since the 1924 collapse.

Specimens of the east edge of 1931–1932 bottom lava were shreddy pahoehoe basalt, black with brown stain, highly vesicular, glassy without visible olivine, with reddish-brown glaze on inner surfaces. The slope of bottom talus was 34 degrees. The cage landed on the talus 250 feet above bottom. Specimen was collected about 3 p.m. The lava ledges at the edge of the floor were about 7 feet high, those out beyond the marginal sag about 40 feet high. Temperature measured at the border ledges, 15-minute exposure, was 73° F., but up the talus with 5-minute exposure was 85°, and at the wall-crack floor edge farther north was insufferably hot; at some places rubber soles were burned. The lava was curled over in shells with cavernous spaces.

The collector noticed "thin air," a difficulty of breathing, about 600 feet below pit rim (bottom 854 feet). This may have been a whiff of sulphur trioxide from the west solfatara.

IMPROVED METHODS, 1932

The staff of the Observatory now included volcanologist, petrographer, engineer, seismologist, recorder, mechanic, and assistant. Attention was given to more field stations, better-distributed instruments, and more precise methods for measuring rim cracks, ground tilt, earthquakes, triangulation changes, level changes, temperatures, and for making maps. The object is to plot change in every variable physical character and to discover new physical characters, having in view a diagnosis of internal symptoms. The prime object of plotting curves is to discover changes that forecast, accompany, and follow eruption.

Halemaumau instrument cellars were increased to three—one north, one west, one southeast. The southeast station was rebuilt December 1931 and houses a two-component smoke-paper seismograph and a clinoscope. The other two cellars are totally underground and contain clinoscopes. The latter were designed here—inverted stiles over a ring plumb-bob. The stiles move on the bottom face of a dial, marked radially and annularly for direction and amount of ground tilt. Readings are made daily, and the instrument set back to center. The three clinoscope chambers around Halemaumau pit, 120° to each other in plan, were made to discover whether tilts are quaquaversal, relative to a central lava column.

A new seismograph hut at Waikii was finished in June 1932 and equipped in October with Hawaiian type smoke-paper seismograph. The elevation is 4700 feet on the west slope of Mauna Kea.

The Kilauea triangulation net, established by Wilson, was resurveyed in 1932 by Wingate, having in view detection of horizontal motion about Kilauea Crater and the rifts.

During September a complete map of Halemaumau was surveyed, 400 feet to the inch, the first to be made of the entire pit since the Wilson map of 1928. The northwest-southeast diameter had increased by having the rim removed with many eastern and northwestern avalanches. Diameters were 3504 feet northeast by 3008 feet northwest. General floor level was 870 feet below southeast lookout. The floor since 1928 had increased in area from 19 to 88 acres, while the upper ring of the rim had enlarged only 4 acres. Mean bottom had risen 280 feet. Fill by lava extrusion since 1928 had been 21 million cubic yards, of which the 1931–1932 eruption accounted for 13 million. The southwest cone was 120 feet above floor level.

The routine of 1932 involved inprovements, suggested to workers at the Observatory as a result of the increased subdivision of labor. Thus the engineer reported in November 1932 on a year of crack measurements. This work had been started with 15 points marked with white paint and numbered on the opposite walls of gaping cracks parallel to Halemaumau rim and close to the trail around the pit. The paint was replaced by copper studs, the measurements were made with steel tape, or at wide cracks with special calipers, and about 35 crack locations were visited every week. Two men are required—one to measure, the other to record. Crack changes correlate with tumescence, tilt, earthquakes, and eruption, and the excessive widening of large cracks close to the rim has coincided with dangerous avalanching as described for January 1929. This has given the crack measurement economic usefulness in warning Park rangers where to rope off portions of Halemaumau rim. Some cracks are stable, some start moving after long repose, and some open and also shift sidewise. Some markers are arranged to measure this.

In March 1932 special postal cards were placed at 25 volunteer stations on Hawaii Island, to be sent to Kilauea Observatory reporting felt shocks. Sixty-one card records were sent in during the year. They show what shocks were general and which were localized. These records help to show the importance of human perception, rather than action on inanimate matter, in evaluating a scale of earthquake intensities. It is desirable to supplement the observer with a simple instruement to cover night hours and times of travel and absence, and also to report very feeble earthquakes.

The petrographer of the station made geological studies in several parts of the island, obtained from Washington new chemical analyses of Hawaiian basalts, and collected specimens.

A new measurement bearing on the emergence of underground water along the shore from the water table of Kilauea and Mauna Loa was conducted in boats at Hilo and in Kona. A salinity survey with apparatus for collecting bottom water and top water out to 10 fathoms was made with hydrometers. Freshness is conspicuous in top water near shore, while at 10 fathoms the top water and bottom water are equally saline. Everywhere opposite the active volcanoes, which are very porous, ground water appears to gush out along the strand line, but springs of fresh water farther out have not been discovered. Apparently the region of active shore erosion is a line of vents for springs. The underground water contributed much to the explosive eruption of 1924. Apparently the collapse of the walls of the volcanic conduit close to sea level promoted inflow of springs which made steam, just as the shore erosion promotes outflow of such water otherwise dammed by mud and sand on the sea bottom farther away.

QUIET PERIOD, 1933

The first 11 months were peaceful for the Hawaiian volcanoes with some increase of seismicity in June–July and a spasm of Mauna Loa earthquakes in October. This last led to an exploration of the summit crater Mokuaweoweo of that volcano November 1. The main crater showed puffing vapor from the 1914 cone, fume was dense from the solfataras near by, and the western walls were dusty showing some fresh scars. A July visit to Mokuaweoweo had shown blue fume, which in the 1914 cone locality was denser and under more pressure in November. This change along with the October earthquakes heralded the coming Mauna Loa eruption of December 2.

EARTHQUAKE TIDAL WAVE MARCH 2, 1933

The seismograph record was put to an economic test in March. A distant earthquake March 2, 7:10 a.m., Hawaiian time (2:31 a.m., March 3, Japan time) made a record indicating distance 3950 miles in the direction of Japan, and the radio broadcast about noon March 2 announced a Japanese earthquake disaster. Harbormasters at 10 a.m. were notified to look for waves from the west about 3:30 p.m. The waves came about 3:20 p.m. in Kona, 3:36 p.m. in Hilo, with a range of 17.5 feet in Kona and 2 to 3 feet in Hilo.

Sea bottom was left bare in the Kona bays, walls were washed down, boats capsized, houses were flooded and moved, lumber was displaced, and goods were washed off wharves. The wharfmasters who took the warning prevented damage. The Honolulu tide gauge showed 20 fluctuations in 4 hours.

North Japan suffered a great disaster from both earthquake and tidal wave, the center being at the Tuscarora Deep 125 miles east of Matsushima. There was great property damage at the northern ports of Japan, where people were wounded and killed.

The basis of the forecast was past experience to show that the elastic wave through the earth took 10 minutes to reach the Hawaiian seismographs, while the water wave, traveling 450 miles per hour, should reach Hawaii 8.5 hours after the earthquake occurred. As the greater earthquakes near Japan write in Hawaii a very distinctive seismogram, and the distance measured is characteristic, it became feasible 2 hours before the news broadcast to indicate accurately the expectancy for 3:30 p.m. The radio announcement added confirmation before the tidal wave arrived.

PUNA TRIANGULATION

Triangulation on the Kau Desert side of Kilauea Crater is described by Wilson (1935). E. G. Wingate began reconnaissance of new triangulation about Kalapana, Pahoa, and Kapoho in Puna along Kilauea east rift in January 1933; in May he occupied 17 stations with a Berger direction transit. Twenty triangles in the scheme had average closure of 1.8 seconds. The object is to detect volcanic ground movement by reoccupation of the triangles. There have been known movements on this eastern rift in 1788, 1840, 1868, 1922, 1923, 1924, and 1938, marked by volcanic outbreaks, unusual earthquakes, shore lowering, or cracks opening. Wilson determined horizontal changes of several feet, after the crisis of 1924, in the net of triangles about Kilauea Crater and the desert south of it. The laying out of such a scheme of stations consumes four fifths of the working time. In Puna two towers were built, 30 and 40 feet high (Pl. 2c), to permit completion of sights within lengths of 2 to

10 miles, over an area of 95 square miles. Two stations north of the rift belt, unlikely to be disturbed, were a base for computations of change. A line last measured in 1914, from existing triangulation, was adopted as a base line for the 1933 work (Volcano Letter No. 400).

HALEMAUMAU LEVELING

Another application of the methods of topographic engineering to volcanology had been started by Wilson in 1921 and 1926 at Kilauea to determine elevation differences by spirit leveling. This was being continued by Wingate in 1933. Thus five bench marks around Halemaumau relative to the southeast Kilauea rim (Benchmark Spit) showed changes between December 31, 1932, and June 12, 1933 (assuming Bench-Mark Spit stationary):

		Feet
B.M. Seis. Cellar SE	up	0.02
B.M. Tourist Stand SE	down	0.05
B.M. Beggar E	down	0.03
B.M. NE	down	0.08
Crack 18 south rim	down	0.33

The accumulated tilt for this period in the seismograph cellar southeast measured by clinoscope was 4.2 seconds southwest.

HORIZONTAL ANGLES

The triangulation method has been applied at Kilauea to single horizontal angles across the Crater and across the inner pit, reading with precision transit from the Observatory concrete monument to permanent flags east and west of the two sinks. The object is to observe secular changes, comparing with tilt, leveling, and crack measurement. Thus we find records for the Halemaumau angles as follows in 1933:

			Seconds
June 20–July 28	38 days	closing	1.2
July 28–August 21	24 days	closing	1.7
August 21–August 29	8 days	open	2.5
August 29–September 5	7 days	closing	0.6
September 5–September 18	13 days	open	1.5

The angle across the greater Kilauea crater gave:

			Seconds
July 28–August 21	24 days	closed	2.5
August 21–29	8 days	opened	0.3

PHASE OF CYCLE CULMINATION, 1933–1935

EARTHQUAKES PREMONITORY, 1933

The seismologist of the Observatory has reviewed (Jones, 1934) 96 earthquake locations on Hawaii, before and after the December 1933 eruption of the summit crater of Mauna Loa. The double net of seismograph stations now included three around Kilauea Crater and three around Hawaii island. About 40 per cent of the recorded quakes were located. A tendency of the quakes to become shallower in origin up to the time of eruption was noted: 14 per cent of the epicenters were submarine, 33 per cent were on Hualalai, Mauna Kea, and Kohala, and 53 per cent were on Kilauea and Mauna Loa. Groups of epicenters fell on lines southeast, northeast, and north of Mauna Loa center. In July, 35 quakes and tremors were in and near Kilauea Crater, and 40 small shocks were caused by motion deep in Kilauea volcano during the year.

May 1933 showed earthquakes about the flanks of Mauna Loa. From August to October they were more numerous and more perceptible along the faults on the eastern flank of Mauna Loa. During the eruption the epicenters were about the Mauna Loa summit crater. As earthquakes, felt by visitors to the crater, were not recorded at Kilauea 20 miles away, it may be inferred that hundreds of unrecorded movements would have been registered if there were a seismometer at Mauna Loa summit.

In October 1933 there was a notable succession of Mauna Loa east flank shocks, which sent an investigation party to Mokuaweoweo, the summit crater of Mauna Loa. The crater showed puffing vapor and fume where the 1933 eruption centered.

1933 OUTBREAK OF MAUNA LOA

This eruption had thus been expected for 6 weeks. During and after it seismic activity migrated to centers away from the crater southwest, southeast, east, and northeast. Mokuaweoweo crater was flooded with lava from December 2 to December 18.

For 3 months the Kilauea observatory tilt had been easterly. It changed sharply to the west during the 3 weeks of release of Mauna Loa's internal pressure and then returned to easterly. The seismic index (Volcano Letter No. 371) changed from 15 to 360 the first week but the third week thereafter dropped to 7.

Kilauea floor apparently swelled upward; the three clinoscopes around Halemaumau had shown inward tilt for many months. The week of the outbreak tilt was 16 seconds outward. After the eruption it was 19 seconds inward for one week. As in 1914, 1916, and 1919 (when the visible lava in Kilauea rose and fell in sympathy with Mauna Loa outbreaks), the plugged Kilauea vent responded by tumescence.

The upper end of the southwest Mauna Loa rift split and vomited up giant fountains west of the southern pits of Mokuaweoweo. Then the main activity moved into the big crater (Pl. 64a) and settled into filling the bowl with 100 feet of new lava beginning 5:43 a.m., December 2, 1933 (Pl. 64b). The fume column, the offset of overlapping source cracks trending across the crater bottom northward, the 70 fountains in lines, and the building up of cones of basaltic pumice all recalled the 1926 outbreak, but the location was farther north in the great crater itself, and the whole eruption expended itself there without flank outflow. A new cascade poured into the South Pit of Mokuaweoweo, adding 70 feet to its bottom layers.

The eruption centered at two cones about 500 feet east of the 1914 cone. The area covered was about 22 square miles. Pahoehoe lava poured east in wide torrents, and Pele's hair lay to westward and fell at Hookena in Kona. The heapings grew into thrones 100 to 200 feet high. December 13 there was only one fountain, and the fill overlapped what remained of the north lunate platform of Mokuaweoweo. The earthquakes of the eruption were felt in Hilo and Kona, but not in Waiohinu or southern places; their origin at the northern rifts was a new feature, confirming the portent of the 1929 quakes to the effect that Mauna Loa was about to enter upon northern outflows. Almost all the seismic activities and outflows from 1903 to 1926 had been in Kau to the south. The last northern outflow was 1899.

MAJOR CYCLES

As the Mauna Loa flow that followed was in 1935 on the north, major cycles of about 33 years had emerged for both Kilauea and Mauna Loa, the latter a decade delayed:

Kilauea	*Mauna Loa*
1790 downplunge	1800 (Hualalai) followed by outflows from Mauna Loa unknown for 20 years
1823 downplunge	1832, followed by northern and southwestern outflows
1855 downplunge	1865, followed by southern and northern outflows
1891 downplunge	1899, northern followed by southern outflows
1924 downplunge	1933 followed by northern outflow
1957 (expectancy)	1966 (expectancy)

YEAR 1934

A party camping on the bottom of Mokuaweoweo, summit crater of Mauna Loa, in January 1934 felt jolts, found hot gas, heard rumbles vertically below, and so demonstrated the creaking and snapping activities of a shrinking lava column after outflow. Gradually the fill of this crater cooled off.

At Kilauea the usual seismic and tilting activities continued. In March the volcanologist addressed the Hawaiian Volcano Research Association in Honolulu on "the coming lava flow," pointing out historical precedents that made a northern flow, dangerous to Hilo, a probability within 2 years of the crater gushing of 1933; it actually came in November 1935. The basis was the history of Muna Loa cycles, but all the data of the Observatory, since 1911, were brought to bear on the economic application of this forecast, and the possibility that aerial bombing might be helpful in diversion at the source if the flow became pahoehoe. In June and August temperatures measured at hot vapor cracks on the Kilauea floor around Halemaumau were lower than those of January 1925 for fissures near the pit. Deeper and hotter cracks were found toward the border of the greater Kilauea Crater. The range of temperatures was from 45° to 89° C. A new trail facilitated making readings north of Halemaumau. Probably the border of the inner fill of Halemaumau, now inaccessible, corresponding in distance from the center to the old "postal card crack" of years preceding 1919, was excessively hot locally. A marked crack, 800 feet back from Halemaumau edge southeast, opened rapidly after April, breaking the road paving.

ERUPTION OF KILAUEA, SEPTEMBER 1934

Halemaumau pit broke into lava eruption along its northwestern floor margin 2:44 a.m., September 6. The 1931–1932 floor lifted with it a west buttress slab of the wall, as the fountaining magma squirted up the wall crack. The result was 25 jets along a horizontal line half way up (300 feet plus) the wall, cascading down in ribbons (Pl. 57a). The extension of this encircling crack descended to the floor edge north where big fountains played up several hundred feet as though from hose nozzles. Sulphurous fume of absinthe red boiled up several thousand feet. The fountain sources were quickly submerged under the spreading lake and from being border jets became interior centers of ebullition. By 8 a.m. the entire floor was covered 60 feet deep. Ten main vents had persisted until 6 a.m. along the cascade crack, when the cascading ceased. The violent northwest fountaining, jetting up 300 feet, stopped rather suddenly at 3–4 p.m. (Pl. 56), when the large lake was covered with black silky skins in concentric bright-line patterns from the fountains outward. On September 7 (Pl. 57b) the lake diminished to a northern circle 1200 feet in diameter with eight fountains. Then the floor lowered and shrank, and the lake became a smaller oval plateau (Pl. 57c) on top of a terraced heap. Spatter banks formed, and the two bigger fountains became wells in cones. Overflows poured out of the lake heap, the floor margins swelled, trickle flows welled up between new floor and talus, and these risings from ring dikes were coincident with lake overflows. Detonation spells accompanied lowerings in the cone wells of the lake. The depression of the floor of Halemaumau was 770 feet. The explosive recessions at a conelet in the remnant lake sent up umbrella-shaped flings of stiff lava 400 feet vertically.

The last moving lava seen in Halemaumau was October 7, and on October 8 the pit walls were sliding, and the lava column was shrinking. The most distinctive feature of this eruption, apart from the high cascades, was the evidence that the whole new crust enclosed a laccolith, with the lake basin on top of the intrusive lens. Then the borders of the intrusion swelled up, made ring-dikes, and changed a cone slope to a flat. The final result was a flattish floor, with the oval remains of the lake surrounded by a rampart, radial cracks across the floor persistent, and two cones in the lake basin with broken-down craterlet wells. The lake was eccentric on the north side of the floor oval. Immediately after the eruption local seismicity was low, but slides were numerous. Stain and fume appeared, and by January 1935 the floor was hot and uneasy, tilts were strong, and snapping noises were heard. Heavy avalanches broke up the black solidified lava cascades of the west wall in April 1935. The avalanching continued and made new talus heaps on the 1934 floor of Halemaumau.

YEAR 1935

Earthquakes were numerous in June and July but declined in frequency in August and September. An ominous series of shocks of prognostic importance, moderate to strong, began September 30 and October 1, 1935. They originated under the rift system of Mauna Loa at estimated depths of 17 to 30 miles. The strong shock at 11:58 p.m., September 30, generally felt, was seismometrically located 17.4 miles deep midway between Mauna Loa summit and the Mauna Kea saddle, where the

Humuula flow was to emerge November 27. One 30 miles deep was 6 miles south of the Mauna Loa summit crater, and one 25 miles deep was 22 miles northeast of it. Another had its epicenter under the northeast edge of the crater itself, where the outbreak began on November 21. The determinations were made by seismometric triangulation from Kilauea, Hilo, and Kealakekua, using the Jones (1935) travel times. There were 178 shocks the first week of October. A spasm of 11 Kilauea shocks occurred in mid-October. Horizontal angles opened as measured from the Observatory across Halemaumau and Kilauea (tumescence?), the Kilauea floor lowered, and the tilt of marginal Halemaumau stations changed from outward to inward.

NORTHERN MAUNA LOA ERUPTION, 1935

Mauna Loa broke into lava eruption at the Mokuaweoweo or crater end of its northeast rift about 6:20 p.m., November 21, 1935. The north bay (Pl. 66a, b) of the summit crater was flooded with pahoehoe lava, and the active crack of the northeast rift belt opened and vomited similar lava from there to a point 4 miles northeast, on the west side (Pl. 66c) of the belt. An earthquake strongly felt at 1:11 a.m., November 21, was located about 5 miles deep, under a point northeast by east, 5 miles from the center of Mokuaweoweo. Supposing the magma split the mountain upward, the lava wedge of the quake of September 30, 17 miles down, rose in 51 days vertically 12 miles, and thereafter in 17 hours rose to the surface 5 miles, because swiftly released by the tension break of the earthquake. This group of agreements between seismometric measurement and resulting location of volcanic outbreak within 2 months' time, coupled with almost exact agreement with published expectation of time and place based on history and cycles, justifies the Observatory method and the prompt publication that issues the warning. The weekly mimeographed reports to the Press are essential for this purpose.

The frothy and flaming pahoehoe squirted up in sheet fountains 500 feet high, at cracks trending northeast practically identical with the sources of 1843 (Pl. 67a). The loss of heat and gas in the first day was great. A line of cones was built. The floods of lava (Pl. 65a), stirred to crystallization thereby turned into aa. Ribbon torrents swept 8 miles due north following the west border of 1843 flow. Within a day the fountaining lessened, and in a week it was replaced by a flank opening (Pl. 66d) to the north. This was between the 1843 and 1899 flows and 3000 feet lower than the first outbreak, which had centered at an elevation of about 12,000 feet. The new vent made quiet fountains in a line, about 10 miles northeast of the top of Mauna Loa. This flow as usual was pahoehoe near the vent, transformed into aa (Pl. 67b) down the slope. The earlier vent near the summit became noisy with viscous ejections, then its lava subsided into the shaft, clouds of yellow smoke puffed up, and sulphur was deposited on its upper cone; in its decline it had covered the slope of initial aa flows with silvery pahoehoe (Pl. 65b).

The lower flow made a succession of high aa fronts down the east side of the 1843 flow nearly to the Humuula (Pl. 69a, b) saddle that separates Mauna Kea from Mauna Loa. On December 22 pahoehoe lava (Pl. 67c) had followed down and overtaken the aa (Pl. 70), pooled in a great lake in the saddle, was blocked on the west by the 1843 fill, and turned a sharp right angle toward Hilo.

The Army was notified in accordance with earlier-made plans, a bombing squadron of the Air Corps on December 27 dropped 20 600-pound bombs (Pl. 68a) on the source torrent which lay at about 9000 feet, and the source tunnels of pahoehoe were demolished. This was 15 miles above the lava-flow front, which was progressing more than a mile a day, in the headwaters of Wailuku River (Pl. 69c), the principal water supply of Hilo. The front was traveling forward 800 feet an hour. Three hours after the bombing it was traveling 150 feet an hour, the next forenoon its speed was 44 feet an hour, that evening it stopped, and thereafter the remnant lava of the tunnel system gushed foward 3500 feet in 4 days, and the flowing ceased on January 2. At the flow source the airplane bombardment had blasted open (Pl. 68b) the roofed channel, and the equilibrium of self-heating with gases was destroyed. The slag dammed itself, spilled on the upland for 2 days, stiffened, slowed down, and solidified into the source vent. Clouds of sulphurous vapor from internal lava boiling in the upper (November) shaft indicated eruptive action until March 1936. A felt earthquake February 5 was recorded 21 miles deep, a smaller one March 22, 35 miles deep, both under Mauna Loa. The sulphur fume cloud on Mauna Loa disappeared in March.

At the rate of uninterrupted progress of December 22 to 27 the flow would have been in Hilo city January 9, 1936, and probably would have filled the harbor to the breakwater or beyond. The flow stopped 8 miles east of the saddle and 12 miles west of Hilo. The plan of blasting source tunnels had been published in June 1931 (Volcano Letter No. 338). Digging and blasting to make a channel hurriedly at Giarre on Etna, after Mascali was destroyed in November 1928 (Volcano Letter No. 211) by aa lava from Etna in Sicily, proved the futility of applying such methods at the front of a flow that had poured down the mountain to the railway in 6 days. An aa flow of first gushing might reach Hilo in a similar time. The Hawaiian plan was limited to pahoehoe that flows in tunnels (Pl. 68c) at the source region. Cooling such a stream by blasting at the vent would make the viscous fluid dam itself and build a new conelet. This would force the continued flowing to the surface of the upland, rob the tunnel supply, and grant a respite to the endangered frontal region. Fortunately all flows form pahoehoe at their source areas.

The first rush that stirs itself to clinker lava, like the November 21 to November 26 gushings of 1935, could be resisted only by an oblique embankment, previously constructed at considerable expense. The 1843 flow, which deflected westward the November 21 onrush, was a natural embankment about 15 feet high perfectly placed. It was a rock wall trending down the mountain in the course of the flow, but sufficiently oblique to the direction of slope to deflect the oncoming streams. Observation of this successful natural deflection from airplane suggested a plan to the volcanologist for the defense of Hilo, with oblique diversion channel and barricade earthworks. This has been the subject (1938–1940) of survey by U. S. Engineers, to defend Hilo harbor from such a sudden rushing flow as the northwestern Mauna Loa aa of 1859, which from an elevation of 11,000 feet traveled 38 miles in 7 days.

By the same kind of argument that made forecast of the 1935 outflow successful, it appears that the doctrine of open north rift and of cycles, comparable to 1843–1859, leaves no doubt that Hilo is in great danger 1937–1957. Its harbor is expensively constructed, its shipping increases, its city contains $50,000,000 worth of property, a railway, and four factories. It is a commercial center of sugar industry. It is the only deep-sea harbor on Hawaii. A lava-diversion channel is the only device that will surely defend it from Mauna Loa.

REVIEW OF HAWAIIAN VOLCANIC SYSTEM, 1909–1935

Plate 86 shows the cycles here cited. The year 1913 ended the cycle 1902–1913' with May 1913 to May 1914 a period of repose. So 1924 closed the next cycle with the engulfment of the explosive eruption. The year 1925 was a repose period. The cycle 1924–1935 ended with considerable volumes of lava into Mokuaweoweo in 1933, Halemaumau 1934, and Mauna Loa outflow 1935. The repose period of the beginning of the cycle 1935–1946 has been prolonged; there were unusual seismic happenings in 1938, but for 3 years there was no supra-marine lava gushing. Each of the three cycles began with repose, was guided to a time of high Kilauea effervescence near the end, and had two or more Mauna Loa outbreaks, one of them crateral, during the 11-year term. The four repose periods were preceded by a measured drop in Kilauea lava of from 200 to 1200 feet coincident with sunspot minima. The exact time of repose transition may be worth determining. The drop of 1200 feet in 1924 was the fifth tremendous lowering in 134 years at four 33 year intervals, and the middle of this period had shown extra maxima of both sunspots and lava volumes in 1855. Time transition determines rhythm. Large rhythms are important in geophysics.

Plates showing in detail the rise and fall of Halemaumau lava to 1916 have been published (Jaggar 1917a, Fig. 1; 1918, Figs. 3, 4; 1920, Pls. 15, 16, 17; Wood, 1917b, Kilauea charts). The profile diagram of surveys indicating rise and fall of Kilauea lava in 1912–1913 inaugurated our knowledge of tidal fluctuations, notably systematic with reference to equinox and solstice. The phase of 1913–1916 introduced the Observatory to the sympathy between Kilauea and Mauna Loa; Kilauea lava rose in 1914 to the time of the summit outbreak of Mauna Loa and then sank. It rose in 1915 to a September spasm of Mauna Loa earthquakes and then sank. It rose in 1916 to the time of a Mauna Loa flank eruption and then sank. And the three sinkings were progressively deeper, after three progressively higher risings; the risings were gradual, and the sinkings sudden (Pl. 75a).

The diagrams by years here reproduced from 1917 onward (Pls. 75, 76) exhibit in the solid columns the height of the liquid lava and in the outline columns the much greater height of the craggy peaks, within Halemaumau, that rose about the borders of the liquid lava lakes. The changes of the two sets of columns express the differential movement between liquid lava and bench lava. The absence of the outline column on some dates means that crag height was not surveyed. On some occasions general lowering and recovery drowned the crags, and in 1923–1924 this became the rule. Crag relief above liquid greatly increased in 1917–1918 and 1920–1921, decreasing notably in 1919 and 1922. In 1923–1924 there were large lakes, and the shores were flat benches. In general the crag selected is the one showing maximum relief; when there is a change, the letters C (central), N (north), and S (south) express which crag is meant. When there are no crags these direction letters refer to pools. These diagrams help express relative depth of pit for any date, and the sequences. The elevations are in feet above sea level, and the general height of the rim of the pit, which changed through the years, is shown by a broken line. The top of the Halemaumau lava column is represented by the highest crag.

In 1917 (Pl. 75b) the crag lava surmounted the pit rim in February, May, October, and December; the liquid executed similar risings, but there was no question of flotation; the liquid could rise while the crag lowered (March 9), or vice versa (August 3).

In 1918 (Pl. 75c) a rise at the winter solstice was prolonged into actual overflow of Halemaumau rim in February–March. The lakes were in cups of the bench magma high above the rim of the pit. The reaction after March equinox was great. This overflowing of Halemaumau to the Kilauea floor was the first since 1894. There are culminations in June, August, and November, the last accompanied by outflow from a vent back of Halemaumau rim on the opposite side from the February floods. Again came a reaction to sinking, but recovery was immediate to a high winter level. This started the immense centrifugal tilt (Pl. 87).

The year 1919 (Pl. 75d), peak of the 11-year cycle and of the building up of the rim, with Mauna Loa outflow September–November, had more or less overflow or outflow from Halemaumau on the Kilauea floor for 9 months from March to November. The lakes and low crags above rim level made a reservoir for outflows. An overflow is where a pool actually spills. An outflow is where a well forms in an outlying crack and spills. Such outflows were from concentric cracks northwest in the summer, from a radial crack southwest in December. Flows several miles long filled the marginal valley of the Kilauea Crater floor both north and southwest. The depression of November 28, 600 feet in 2 or 3 hours, was followed by instantaneous recovery at unprecedented speed to the time of outflows that split the mountain. For the first time since 1868 the Kau desert received a lava flow, at the end of December. The overflows and outflows of Kilauea and Mauna Loa in 1918 and 1919 had now unweighted the lava column of the Hawaiian system, the gases had escaped, and the progress had been from Mokuaweoweo in 1914, Puu o Keokeo 1916 and 1919, Kilauea floor 1918–1919, and now Kau Desert 1920. The sequence from top of the island downward to lower fractures was unmistakeable. The weight of the refuse was borne by the crater floors and by the outer island.

The year 1920 (Pl. 76a), with outflow for 7 months on the southwest Kilauea flank, inaugurated a superb series in Halemaumau of downward plunges of the lava column 1921, 1922, 1923, and 1924, accompanied by overflows and outflows, with most resilient recoveries. The Kau desert outflow of 1920 pulled down the Halemaumau column in January. During the months of adjusted outflow (March–May) that built up Mauna Iki hill in the desert 6 miles away, Halemaumau recovered and in July–August lost ground again. When the outflow stopped in August, pulsations of recovery to the usual December rise took place. This became another time of floods of outflow (December 27) in Kilauea Crater, but the southwestern Kau desert rift was sealed. The crags were now immense and were destined to reach their maximum relief in 1921, as the liquid pumped itself up and down in the wells, each recovery causing the semi-solid paste to rise in vertical pencils or filaments even faster than the liquid foam. These great crags were somewhat similar to the Pelé spine. The letters N, C, and NE on the diagram mean that the north crag became dominated by the central crag, and this in turn was surpassed in height by the northeast crag.

The year 1921 (Pl. 76b) repeated the phenomenon of two strong risings and two depressions with the liquid lava more than 300 feet below the rim of Halemaumau. This year, close to the peak of the cycle (a debatable time determination), was exceptional in that the risings occurred near March and September equinoxes, and depressions were seasons of solstice. The outstanding event of the year was the colossal effervescence of gases in the March rise, with overflow and outflow from Halemaumau filling the entire south end of Kilauea Crater and escaping through a low pass by a short flow into the desert. The incandescent wells southwest in the floor of Kilauea crater, close to Halemaumau on the line of the rift, were apparently backed up by the sealing of the Kau Desert crack of 1920; the energy of repeated effervescence, and tumescence of the crag lava, expended itself within the lips of Halemaumau itself. The year 1921 was a year of upbuilding within Kilauea Crater, after the southwestern Kau Desert end of the rift that crosses the crater had plugged itself, and before the eastern Chain-of-Craters extension had opened.

During 1922 (Pl. 76c) the gas release of overflowing the highest part of the rift at Halemaumau itself had ended, but the rising of sluggish lava with uniform lift of crags was steady throughout the spring. This was ended in May by escape of the lava in Makaopuhi and Napau pits of the Chain-of-Craters and an extreme collapse of Halemaumau. This recalled the similar collapses of November–December 1919, when the southwestern end of the rift was breaking open. The 1922 downplunge of over 800 feet went 200 feet lower than in 1919, with cauliflower clouds of dust rising. The pit Halemaumau was a funnel of debris. Such splitting open of the east rift to emit lava had not happened since 1840. As the rift is a unit through Kilauea from southwest to east, with a bend at the sink, the sequence of 1919–1922 was escape and freezing southwest, escape and weighting in the crater, and now escape and pit outbreaks east, to be succeeded by more eastern splitting all the way to sea level and beyond in 1923–1924. The autumn recovery of 1922 was sluggish inward trickle at Halemaumau after the Chain-of-Craters ceased action, and this year saw the last of the crags.

The year 1923 (Pl. 76d) inaugurated flat floors and pools in Halemaumau pit, in contrast to the impressive crags that are illustrated in the photographs and shown in their changing relief above the liquid lava lakes in the diagrammatic profiles from 1917 to 1922. The absence of uplifted border crags from January 1923 to the high level of January 1924, during two voluminous inrushes of liquid lava succeeded by ruptures of the eastern rift of the mountain, appears to mark intense release of magmatic gas with its heating and melting effect, just before the enormous collapse of the end of the 11-year cycle in 1924.

The high level of May–June 1923 was a strong ebullition rivaling in brilliancy March 1921, and the lowering of August was accompanied by outflow in the forest near Makaopuhi on the eastern rift. Halemaumau was not vacated by the lava with any such internal collapse as in 1922. The rise of the Autumn led to extraordinary oscillations in December 1923 and January 1924, with big fluctuations of level within single days, changing source wells and sink-holes, and tumultuous fountaining and cascading down the wells. The development of two climaxes per year had been marked in 1920, 1921, 1922, and 1923. The culminations were near solstice with the exception of 1921. The suggestion of a semiannual solar release in the general progress of the breaking open of the east rift of the mountain is conspicuous in these diagrams.

In round numbers of feet of depression we get the following for Halemaumau:

	Feet
November 1919	600 after downplunge
February 1920	350
August 1920	325
July 1921	325
November 1921	375
July 1922	875 after downplunge
January 1923	625
August 1923	550 after downplunge
April–May 1924	1325 after downplunge

For the lower stands of the lava, notable downplunges accompanied the outflow of the southwest rift in 1920 and the breaking open of the eastern extension of the same rift the other side of Kilauea Crater in 1922 and 1923. Breaking open the flank of the mountain pulled down the lava in Halemaumau pit. With the great lowering of April–May 1924 and the observed rupture of the rift at that time in Kapoho at the shore line, the fracture extended itself to the concealed mountain flank under the ocean, and outflow of lava occurred there, with science powerless to observe it.

The year 1924 (Pl. 76e) was characterized by the very large lake of lava from wall to wall in Halemaumau pit in January. The rift broke open far to the east in February, March, and April, the break reached the shore line of the island, the lava through these months steadily lowered to obscure depths in the pit, and in May came the explosive eruption. The appearance of recovery in the talus of the bottom of the pit for the survey of May 17 was due to the higher bottom occasioned by the choking fill of avalanche debris. This again lowered, but none of the surveys of that time was precise.

The remainder of the diagram from 1925 to 1934 inclusive exhibits the entirely new feature of inflow of lava periodically with intensely effervescent fountains around the edges of the inner plug. The pit was a funnel of talus, and each eruption lasted a few days or weeks and added a series of progressively wider oval layers to the bottom. There were interruptions to Halemaumau progress that were introduced for the whole Hawaiian system by release of large volumes of lava at Mauna Loa in 1926 and 1933. For both these times Halemaumau shows 3 years of undisturbed bottom. Mauna Loa had its great eruption that culminated the 11-year cycle in 1935–1936. If the diagram were extended, the next 4 years for Halemaumau would be like 1934, and again the system by its activity at Mauna Loa showed interruption to Halemaumau progress. The stagnation at Halemaumau of 1935–1939 was a prolonged repose period after the end of the cycle.

The different aspect of these years shown by the diagram 1909–1935 (Pl. 74a), which exhibits coincidence of Halemaumau stands with the several eruptions of Mauna Loa, is that this diagram exhibits maximum stands of the lava in Halemaumau, and the data by quarter-year intervals. The quarter-years selected are those centering about the months of equinox and solstice. We see that 1913 and 1924 were depression maxima at each end of an 11-year cycle, while 1919 was the maximum of the elevation of the lava, with both Mauna Loa and Kilauea participating. The cycle 1924–1935 reached its culmination of lift of lava in 1933–1934 for both Mauna Loa and Kilauea. The end of the cycle by lowering may have occurred under Mauna Loa after the 1935 eruption and by avalanching and inward shrinkage measured by leveling at Kilauea Crater; but the Kilauea lava column was a frozen plug that did not go down. The whole habit of the 11 years 1925–1935 at Halemaumau was different from the preceding 11 years. The preceding cycle fulfilled itself at the end of the 134 years since the last explosive eruption, as a time of mobile lava column freely lubricated in the shaft. The succeeding cycle was the beginning of upward march of the lava column by spasms after the enormous quenching of 1924, so that high mobility in the Halemaumau column may be deferred for some decades. Probably this happened after 1790. During this 1925–1935 cycle Mauna Loa, however, has executed three strong effervescences even more voluminous than its three of 1914–1919. The great collapse of Kilauea in 1924 did not prevent Mauna Loa in 1926 from showing full vigor of lava emission at the summit and on the southwest flank. As this was succeeded by the gushing of Kilauea almost annually thereafter, and as Kilauea had demonstrated its capacity for immediate lava recovery in July 1924, both volcanoes probably have their lava reservoirs at different levels always available, but in some sympathetic, but not strictly hydrostatic, relation of gas pressure to the deep sources. We have to deal with connected cracks and plugs and gas-charged glass confined; in a chemical laboratory the analogy would be connected tubing and cocks, and gas-charged fermented liquor confined. In both cases opening a vent releases froth or foam, not a simple liquid. The hydrodynamics of foams would make a valuable experimental investigation for conduits of varying size.

PART 3.—KILAUEA STEAM BLAST ERUPTION, 1924

INTRODUCTORY STATEMENT

The narrative of this so-called explosive phase (Jaggar and Finch, 1924; Stearns, 1925; Finch, 1924, 1925; Bulletin, May, June and December 1924, Jan.–Mar. 1926, Volcano Letter No. 328, 1931) has been published and illustrated with photographs in the Bulletin and the Volcano Letter. The publications cited explain the quantitative measurements whereby the material lost from the wall of Halemaumau was much greater than all the ash that fell (Bulletin, December 1924). The sequence of events from 1921 to 1924, wherein Kilauea split open its east rift to the ocean shore and beyond, demonstrates that the steam-blast eruption was incidental to a drainage outflow of lava under the ocean east of Hawaii, and collapse inward of the pit wall matter.

The sequence was (1) lowering of large volumes of lava January–March 1924, (2) rupture of east rift at shore line April 1924, (3) outflow probable on same rift completely submarine and concealed, April–May 1924, (4) collapse of Halemaumau walls into the emptied dike chasm May 1924, (5) spasmodic inrush of ground water at very low levels along the dike chasm May 1924, (6) rhythmic steam blasts through Halemaumau by alternation of avalanche choking and ground-water boiling, May 1924, (7) back filling of dike chasm with lava when submarine outflow was ended, to July lava eruption in Halemaumau bottom, and sealing off of ground water, June–July 1924.

The full account of the observed phenomena during the actual avalanches, flinging out of rocks, electrical and incandescent effects, and observation of the seismographs, is recorded by the diary of professional and volunteer observers in the document that follows. This record is remarkable in collecting the observations of a dozen scientific observers for 3 weeks of continuous note-taking night and day, on the edge of a large volcanic sink, looking *down* at the inner pit of an explosive eruption. Moreover some of the observers repeatedly visited the edge of this inner pit Halemaumau during the progress of the explosions, timing their visits so as to arrive after a major blast had left things relatively safe.

Volumetric enlargement of the pit was enormous, but the thickness of fallen ash was slight (Bulletin June, July–December 1924). Vapors rising were pure steam and totally unlike the flaming hydrogen and noxious sulphurous gases that come off the lava fountains. Here was Kilauea behaving like Bandaisan. The eruption made agglomerate that consisted of the diverse rocks of the pit wall. The eruption made ash that was the powder of avalanches. The cauliflower clouds were typically vulcanian, but when the dust settled pure white steam remained.

The seismic effects of the eruption (Bulletin, May 1924, p. 38; Finch, 1924) revealed harmonic tremor for the first week of the eruption, a phenomenon characteristic of deep lava surging. Presumably lava fountaining in the depths, as pressure was released by the submarine outflow, was here recorded instrumentally. This agreed with the observed flinging out of fresh lava bombs in the steam eruption of 1790, when the initial fountaining must have been higher. It agreed also with the intense fountaining of December 1919 that preceded and accompanied the visible outflow from Halemaumau to the Kau Desert. Here was an additional index of lava outflow, added to the sequence (1) Kilauea floor overflows and outflows 1921, (2) Chain-of-Craters outflows 1922, (3) Chain-of-Craters outflows 1923, and (4) Chain-of-Craters extension rupture to the seashore April 1924. The seismic centers were migrating east along this rift. Some of them were under the sea at distances greater than the length of the rift line above sea level, but the seismographic data have not yet been investigated with modern travel times. Here are seismograms demanding future research.

To make clear which hours of the diary were coincident with explosion spasms the following list is useful:

LIST OF EXPLOSION SPASMS OF HALEMAUMAU, 1924

May 10	6 a.m. ?–10 p.m.		
11	10 a.m. ?		avalanches W. and SW.
12	?		" decreased.
13	5:30 a.m.	2:30 p.m.	" S. rim.
	7:10 a.m.	4:00 p.m.	
	8:00 a.m.	4:57 p.m.	
	9:35 a.m.	5:20 p.m.	
	12:15 p.m.	5:33 p.m.	
	1:00 p.m.	6:32 p.m.	
		10:00 p.m. about	
14	9 to 10 a.m.		
	3 to 4 p.m.		
	10 to 11 p.m.		S. rim falling.
15	11 a.m.		
	6 to 11 p.m.		
16	11 a.m. to 12 noon		
	2 to 3 p.m.		
	5 to 6 p.m.		
	9 to 11 p.m.		
17	1 to 4 a.m.		
	12 to 1 p.m.		Rim back 200 feet SE, E, and NE.
	6 to 9 p.m.		
18	2 to 5 a.m.		
	11 a.m. to 1:30 p.m.		
	7 to 9 p.m.		
19	4 a.m.		
	11:50 a.m. to 12:50 p.m.		
	5:40 to midnight		avalanches 5:45 p.m.
20	Diminishing explosion 1 a.m.		
	7:39 a.m. Small		
	12:45 to 2 p.m.		
	4:30 to 5:30 p.m.		
21	Probably 2:17 a.m.		6 a.m. crevasses seen N. rim and rim S. side 600 feet back heavy avalanches
	7 to 10 a.m.		
	4:54 to 5:18 p.m.		
	9:01 p.m.		

22	Probably 2 to 3 a.m.	
	8 to 9 a.m.	
	1 to 3:30 p.m.	all rim back 200 to 300 feet in two days
23	3:30 a.m.	
	8 to 9 a.m.	
	3:30 p.m.	
24	8 to 10 a.m.	
	2 p.m. Small	
25	7:29 a.m.	
	11:21 a.m. to 12:32 p.m.	
26	Early morning.	
27	9:35 to 10:30 a.m.	

THE TABULAR SUMMARY

GENERAL STATEMENT

The following tabular view exhibits zeros which do not mean absence of the phenomena on the days in question but absence of observations. The figures are those therefore that rise above a more or less uniform minimum, dependent on an approximately uniform system and place of recording. There were some explosions, and falls of at least light stones, every day from May 10. Those recorded were seen or heard, mostly from the Observatory, and also from Uwekahuna Bluff May 14, 15, and 16.

By "number of exposions" is meant explosive spasms. The table shows that on May 13 they averaged 12 hours apart, and thereafter from 6 to 12 hours apart. The mean was 8 hours, or three spasms a day, from May 14 to 23.

Intensity of explosion is based on an arbitrary scale, making May 18 "grade 10," and the first ejection of May 10 is called "grade 1." In each day the maximum explosive spasm determines the grade for the day.

"Stone-fall" means showers of stones seen either glowing at night or raising dust by day, or heard making a patter on the hard floor of the big crater, or observed boulders making a trajectory with a trail of dust. The figure given is the number of separate times for the day such happenings were recorded.

Duration of explosions refers to number of hours single explosive spasms lasted, often composed of numerous gas rushes repeated at intervals. The figure is for the longest spasm of the day. The evening of May 19 produced continuous explosion and continuous seismographic tremor, but the intensity maximum of concussion and violence had been passed on May 18.

By "electric storms" are meant thunder and lightning, one or both, number of times noted for the day.

Felt earthquakes are those classified as slight, moderate, or strong, generally felt at the Observatory by persons on watch. The figure is the number for the day, and the list provides a rough intensity curve of seismicity for the eruptive period.

"All earthquakes" include these, and all the instrumentally registered shocks, in-so-far as they may be separated out on the seismogram from the prolonged tremblings. Here again numbers per day are shown, producing a frequency curve of seismicity.

The list of mud rains includes a few separately recorded spells of raining with pisolites, sand, dust, and lapilli at the Observatory. This list is incomplete as it takes no account of the many showers to leeward of the pit, and the showers were notably local and scattered.

The same imperfection of record attends the caving in of the rim of Halemaumau. There was unmistakeable subsidence of the rim southwest first, this being the side of the Kau Desert rift tunnels of 1920, and of the great enlargement of 1922. The collapse after southwest breakdown proceeded in order around the circle to the south, southeast, northeast, and north; the balancing of the breakdown to the northwest and then evenly all around the previous outline of the pit (for the new outline is everywhere about 700 feet back from the outline of April, 1924) was accomplished during times of maximum explosion, maximum duration of spasms, and maximum intensity of earthquakes. On May 21 and 22 the collapsing by incessant avalanches was observed and recorded as the maximum breaking down of the walls.

These figures are of interest when plotted (Bull., May 1924; Fig. 16). Here the maxima of ejection violence clearly correspond in time to a depression between two maxima respectively of numbers of explosive spasms and of seismic phenomena. The maximum number of spasms comes near the beginning, the violent crisis in the middle, and the earthquake intensity and greatest frequency near the end.

This probably means that the eruption began with 2-hourly rhythmical pulsations of steam release. Collapse of pit blocked the steam, and violent ejection at longer intervals ensued.

By May 19 the throat was cleared, and prolonged release was permitted. By May 22 the pit had collapsed, and the greater sink or crater of Kilauea outside was weakened and slipping. By readjustment of the mountain blocks, this produced the seismic maximum.

The data of Table 1 are published as curves (Haw'n. Volc. Obs'y., Bull., May 1924, Fig. 16). The curves show the maxima of frequency of explosive spasms May 13, of intensity May 18, of falls of stones and duration of spasms May 19, of electric storms May 17–19, of felt earthquakes May 22, and of earthquake frequency May 24.

May 28 produced 64 shocks, May 29, 92, May 30, 130, and May 31, 35. The tilting of the ground at the Observatory on the northeast rim of Kilauea Crater, always in directions south and south-southwest, for successive weeks beginning with the week ending April 26, was systematically accordant with the crateral collapse, *viz.*, in seconds, 1.0, 3.8, 11.0, 20.1, 15.5, 12.5, 4.3, 4.7; making total seconds tilt in 8 weeks 72.9 seconds. Then tilt of June 15–21, 3.2; and June 22–28, 2.5 seconds in reverse direction north-northeast.

Comparing Mr. Finch's note of tilt and strong quake herein 8:42 a.m. May 30, it will be seen that this time is when lava was computed (Jaggar, Bulletin 1924, p. 118) to have passed sea level in its upward progress to recovery and inflow in July.

LOWERED ELEVATION WITH TILT, 1924

The above figures drawn from direct observation of the weekly change of position of the pens of the Bosch-Omori seismographs in the basement of the Observatory,

TABLE 1.—*Summary of Explosive Eruption of Kilauea, May 1924*

May	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
Number of explosions	2	1	0	13	3	2	4	3	3	3	3	4	3	3	2	2	1	1
Intensity 1–10	1	½	0	3	2	3	5	8	10	6	3	2	2	3	4	2	½	¼
Stone-falls	0	0	0	1	2	1	4	4	6	10	2	0	2	1	2	0	0	0
Duration explosion (hrs)	¼	¼	0	3	1	5	2	3	3	7	1	½	2½	1	2	1	½	1
Electric storms	0	0	0	1	0	0	1	3	3	3	2	2	2	2	1	1	0	0
Felt earthquakes	3	3	8	24	17	15	45	30	25	21	41	50	75	59	67	45	19	36
All earthquakes	101	111	59	88	113	132	276	150	165	180	210	275	339	257	467	248	156	195
Mud rains	0	0	0	0	0	1	2	3	3	2	0	0	0	0	0	0	1?	0
Caving rim direction	0	SW	SW	S	S	?	SE	NE, SE	all	all	all	N, all	all, max.	?	?	?	?	?

on the northeast rim of Kilauea Crater, indicate that the fault block, on which the Observatory is built, was tipping inward as the plug of the larger crater subsided. The ground around the Observatory and Volcano House was also subsiding, but less rapidly than the Kilauea Crater floor which surrounds Halemaumau. The facts of seismometrically recorded tilt and of lowering of the outer crater rim have been reviewed (Jaggar, 1920; Jaggar, Finch, and Emerson, 1924; Jaggar and Finch, 1929; Bulletin December 1924; Wilson, 1935), and the data accord with measured changes of uplift and lowering made at Usu and Sakurajima volcanoes (Jaggar, 1920, p. 205; Omori, 1911; 1914) in Japan. The observed tilt acting on seismographs appears especially in the last half of the narrative diary.

In Plate 87a is exhibited the compiled result of studies of the Observatory seismograms for change of tilt from 1913 to 1930. This was compiled by R. H. Finch and H. A. Powers from the seismograph records and is less accurate from 1913 to 1917 than it is for the years following. It follows the general method used by Knott (1908, p. 189; Bulletin, December, 1927, Fig. 48) whereby the change of tilt from month to month is expressed as though a wand stood upright on the earth's surface with its upper end under a horizontal sheet of paper disconnected with the earth, and for its mean position each month it stamped a dot through the paper for its departure from the vertical, with magnification to the scale in seconds shown. Two arrows indicate respectively the directions of Mauna Loa summit crater and of Halemaumau from the instrument at the Observatory. The diagram is oriented on the meridian.

The obvious significant tilting of the ground that it shows is for each year to execute a clockwise loop; for the period from July 1913 to July 1918, to show eastward tilt during the Mauna Loa eruptions; for the period July 1918 to November 1920, to show excessive northward tilt during the Kilauea overflows; and for the period November 1920 to 1927 and thereafter, to show south-southwest tilt during the East rift outflow and Halemaumau collapse, of the same excessive magnitude that had occurred between April 1915 and November 1920 in exactly the opposite direction. This order of magnitude had been about 85 seconds of change of the plumb line.[9]

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[9] The tilting of the ground under the Hawaiian Volcano Observatory is detected and recorded by daily measurements from the seismographs. At about the same time each day the position of both the north-south and the east-west pen relative to a fixed point on the support of the recording drum is measured in millimeters. The movement of each pen with respect to this point is caused by a slight swing of each seismograph boom, when its supporting pier is tilted in a direction at right angles to that of the boom. This inclination is brought about by the tilting of the ground, and the two planes of suspension resolve the total tilt into its rectangular components. These movements in millimeters, convertible into seconds, are plotted for each day's positions on co-ordinate paper, using the measured position of the pen recording north-south tilt as the ordinate and that of the pen recording east-west tilt as the abscissa. The zero of the chart is arbitrary, as its design is wholly for showing relative tilts.

Plate 87 has had its curve smoothed by the following method of arriving at the position of the monthly mean co-ordinate points, and then connecting these with straight lines. First, an average position for each month was obtained by an algebraic summation of all the daily co-ordinates in the month. Then the points were obtained by computing overlapping 5-month means (Knott, 1908, p. 106–154). Thus the plotted position for each month represents the average position during the 5-month period, of which the month in question is the middle member. The curve shows the tilting of the ground due only to forces of several months' duration, such as swelling and shrinking of the mountain accompanying major intrusions of lava, and expansion and contraction due to seasonal climatic or solar gravity stresses. Short-period tides, daily or weekly temperature effects, and sudden surface movements of lava are smoothed out of the curve by this treatment.

Other graphs are prepared for each year (Bulletin, December 1927), smoothing the daily tilt movement by computing

The truly extraordinary south-southwest tilt toward the crater, of 87.73 seconds change of the vertical at the Hawaiian Volcano Observatory shown by this averaged chart of Plate 87, for the long-term period November 1920 to May 1927, including the May 1924 steam blasts and Halemaumau engulfment, accompanied measured lowering of the entire top of the mountain. This was measured by critical leveling of R. M. Wilson, October 1921; and of U. S. Coast and Geodetic Survey, levelman Lt. L. G. Simmons (Bulletin, June 1927) followed by Mr. Wilson, in May 1927 (Wilson, 1935, p. 31–56, Fig. 8). These were from tide-gauge datum stations along level nets adjusted by least squares.

The Volcano House bench mark on the northeast rim of Kilauea lowered 3.56 feet, and Puu Koae in the Kau Desert 5 miles southwest of Kilauea lowered the same amount. East of Halemaumau rim, Kilauea floor lowered 12.99 feet at the bench mark Little Beggar. The west bluff of Kilauea Crater lowered 6 feet. From the Halemaumau center of collapse outward for 5 miles are graduated contours of lessened lowering. Kilauea Crater was a center of a funnel of depression at least 15 miles across, with 1 to 14 feet of lowering from the periphery of the sunken area to the edge of Halemaumau pit. Horizontal movements measured by triangulation between 1922 and 1926, for radius of 1 to 5 miles outward from Halemaumau, show vectors of centripetal displacement 1 to 5 feet, with maxima close to the Pit.

Correspondence among centripetal tilt measured seismographically, centripetal lowering of elevation measured by tide-water leveling, and centripetal vectors of horizontal displacement measured by triangulation is complete for 1921–1922 to 1926–1927, and the week-to-week data of May 1924 indicated that the greatest unidirectional tilt movement toward the center coincided with the collapse of Halemaumau of that period.

The radial distance of depression effects 1921–1926 northeast across country, along the Hilo road from Halemaumau, was

At 3 miles	3 feet of lowering
At 8 miles	2 feet of lowering
At 14 miles	1 foot of lowering
At 22 miles	0.5 foot of lowering

At Hilo 31 miles, probably slight depression of tide gauge.

At Kapoho near the east point of Hawaii, at the shore-line extension of the Kilauea east rift, the sea coast sank about 12 feet (Finch, 1925), and the ocean flooded the seashore vegetation in April 1924. This is not far southeast of Hilo, and Hilo is only about a third of the way down the true mountain to the deep ocean floor. We have discussed elsewhere (Jaggar-Finch, 1929, p. 43) the volume of approximately 750 million cubic meters of space voided inside the mountain that the engulfment and dish of subsidence would represent as land withdrawn downward, but this assumed a symmetrical circular figure like a lens. The first supposition was the drainage of a sill thickest beneath the crater. Wilson's contours of change (Wilson, 1935, Fig. 8)

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overlapping 7-day means. The position given for each day is actually the average position for the week of which the day is the middle point. This smoothing tends to minimize the effect of daily temperature, errors of reading, instrumental errors, and small earthquake tilts followed by rapid recovery. These curves of plumb-line change are filed among the Observatory records (Pl. 87b).

are crowded on the west bluff side and angular toward the east and southwest Kilauea rifts, suggesting that the drainage was down dike chasms under those rifts. This would accord with the filling and overflow of those chasms in 1920–1923.

If we imagine fault blocks angular in plan at the crater, like those from the top of Mauna Loa down to Kilauea and beyond, then the one between Kilauea and Hilo might be very old and so pivoted in depth as to tilt toward Kilauea or toward the southern sea, when the dike chasms drained. A reason for suspecting this is that thermal waters abound along the east and southwest rifts, but at Olaa Mill two voluminous producing wells from 15 feet above sea level have no thermal quality whatever. This is on the Hilo block. The graded subsidences from Hilo and from Kau Desert would then become slumping of fault blocks toward the Kilauea engulfment, which in turn would be dike drainage to eastern submarine outflow. The solid geometry of such a slump might be tectonic or isostatic adjustment, motivated by lava withdrawal, but not an exact volumetric equivalent of land withdrawn and lost pit lava. The weekly tilts to the south of March–April–May 1924 are as much a tipping seaward of the fault block as a tipping inward of the crater wall, for they are measured only at the Observatory cellar.

CENTRIFUGAL TILTING, 1915-1920

The earlier tilting (Pl. 87a) for the general progress of inclination of the ground in the Observatory cellar to the north-northeast from April 1915 to November 1920 is of importance. The charted return to eastward tilt and annual loops after the inflow of lava to Halemaumau of July 1924 brought the tilt position of the seismograph pens in January 1927 to exactly the same place on the chart that it had occupied at the beginning of the northward tilt in April 1915. Thus it took 6 years for the northerly centrifugal tilt to reach the tremendous gushings of overflow in Kilauea Crater January–March 1921, and 6 years thereafter, at the end of 1926, the lowering and inward tilting had gone hand in hand at the volcanic center, to restore the condition of the beginning.

Moreover, most of the northward tilt on the diagram occurred rapidly in a straight-line movement following June 1918 just as the greater straight-line tilt of the crisis of 1924 was done in 7 months following January of that year. The year 1918 (Pl. 87b) inaugurated 4 years of overflow accompanying this tumefaction in Kilauea Crater, just as 1920 inaugurated 4 years of collapse with outflows in both directions from the flanks of Kilauea mountain.

Mr. Wilson's analysis of the unquestioned lowering of the top of the mountain around the crater we have discussed as reported in his monograph on leveling and triangulation for the period of collapse between 1921 and 1927. Between 1912 and 1921, when tumescence was clearly in evidence at the edge of Halemaumau, and tilt instruments confirmed the presence of this process, Mr. Wilson made the following remark with reference to his Figure 6.

> "From an inspection of lines marked 1912, 1921, and 1926 on the diagram, the first thought is that the ground of Kilauea was elevated about three feet between 1912 and 1921, and then dropped back to its original position by 1926."

Owing to the fact that the rods of 1912 used for leveling were incompletely known, were not made of invar, and the complete record of the methods of checking rod length with steel tape as used by J. M. Rawls was not available, these methods having been precisely recorded in 1921 and 1926, Mr. Wilson re-examined the possibility that the wooden leveling rods of 1912 changed length due to moisture, as they were found to do about 1921, and they may or may not have been tested with steel tape in 1912. If an empirical rod-length error due to moisture is applied to the 1912 survey, the heights of all the bench marks from Olaa Village (Keaau) to the Volcano House come out almost identical with the survey of 1921.

Bulletin No. 561 of the United States Geological Survey *Results of spirit levelling in Hawaii, 1910–1913, inclusive*, published the 1912 elevation of Volcano House as 3973.090 feet. Wilson's elevation in 1921 for the Volcano House was 3976.103 feet. This difference suggesting elevation of the northeast edge of Kilauea Crater by 3.013 feet between 1912 and 1921 is so extraordinary as to be doubtful fact for engineers, though it is common enough fact for volcanologists, who know the measurements made before and after seismic and volcanic events in California, Alaska, and Japan (Imamura, 1930). Mr. Wilson makes the following statements in his monograph (1935), which appear to justify a critical comparison of his engineering data with the seismograph tilt data, in order to weigh the question whether the Volcano House bench mark rose 3 feet between 1912 and 1921.

Mr. Wilson writes

> (page 6) "The writer has made no attempt to translate the discovered displacement into terms of geologic or volcanic significance."
>
> (page 44) "The possibility of discovering real changes in elevation up the side of the mountain from Keaau to Kilauea seems to depend almost wholly upon this question of rod length."
>
> (page 50) "By this reasoning (rod length) it does not seem possible to state with certainty that an upward displacement in elevation occurred between 1912 and 1921. There may have been such a displacement, but if so it is masked by the uncertainty of rod length."
>
> (page 53) "There are many different possibilities that are offered through different interpretations of tide water observation, rod length corrections in the lines from tide water or other elements, involved in attempting to obtain for reference an elevation to approximate the absolute at Kilauea. Thus it is possible for any individual to choose a datum according to his own interpretation of these elements."

Wilson has evidence that definite changes in elevation of the local leveling circuit from Volcano House to Cone Peak in the Kau Desert between 1912 and 1921 occurred in graded amounts, treating the Volcano House datum as unchanged. For this he publishes a map of the crater, showing elevation differences and contours of change, indicating that the lava plug settled so as to make the center of Kilauea Crater go down 3.8 feet between 1912 and 1921, while the upper part of the Kau Desert had risen just where the December 1919 rift cracks opened from 5 to 10 feet, preceding the Mauna Iki lava flow. The map shows a symmetrical domelike bulge centering about mile south of Cone Peak, or about 2½ miles southwest of Halemaumau, with a maximum displacement upward, relative to the Volcano House bench mark, of 1.6 feet. Thus we see that Wilson recognizes crateral swelling not affected by rod length between 1912 and 1921; he recognizes doubt about the possible elevation of Volcano House in that interval and he measures definite subsidence of the Volcano House 3.56 feet between 1921 and 1927. With this depression we have correlated measured change of tilt southward at the Observatory of 87.73 seconds between 1920 and 1927, and the Observatory instrument is approximately 300 feet southeast of the Volcano House bench mark on the edge of the same cliff bounding the northeast wall of the greater crater.

If tilting of the ground at the Observatory between 1912 and 1921, in the opposite direction to the tilt of 1921–1927, has been shown to have occurred as above, if it agrees with volcanic events, and if the amount of tilt is apportionate to the supposed elevation of Volcano House bench mark of 3.013 feet in this interval, using the 1921–1927 tilt in the opposite direction as a scale of reference the evidence shows that the rod-length moisture corrections were not applicable and that the 1912 elevation in Bulletin 561 of the U. S. Geological Survey were correct.

We may conclude from Plate 87a and b that the top of Kilauea mountain rose about a meter during the intense northward tilting of the Observatory from April 1915 until November 1920, as did Usu volcano in 1910 and Sakurajima in 1914 (Imamura, 1930). This at Kilauea was followed by a negative movement of like amount from November 1920 to May 1927, accompanied by angular southward tilt of the Observatory ground of like amount, 85 to 87 seconds. Northward is away from the crater, southward is toward it. Such were the massive and prolonged forces that tumefied and depressed a volcano 4000 feet high during the magmatic efflux and withdrawal that had its violent crisis in the steam-blast eruption of which the following is the hour-to-hour diary.

EXPLOSIVE ERUPTION AT KILAUEA CRATER, 1924

CHRONOLOGY BY DIFFERENT OBSERVERS

General statement.—A document not hitherto published, showing details observed by R. H. Finch and the official and volunteer observers whom he organized. This was during the enlargement of Halemaumau by engulfment. The measurements and observations were kept up, through continuous occupation of the Observatory on the northeast rim of Kilauea Crater, and through repeated visits to the inner pit, and by excursions for special surveys.

May 9, Observer Emerson at pit

Considerable increase in the rate of subsidence, with continuous rattle of avalanches. During the morning the bottom could be seen, but after noon pit was so full of smoke that nothing could be seen. There appeared to be no material change in the cracks back of the rim of the pit. During the morning considerable aa paste was visible where avalanches tore away large surfaces of the cliff faces. The heat was very noticeable.

May 10, Observer Emerson at pit

Volume of dust clouds rising from pit tremendously increased; an impressive sight from Observatory at 6:30 am. Took series of photos then (3). Went down to pit, nothing visible because of constant rising of dust. Continuous rorar of avalanches. No collapse of walls. Most of the time the dust clouds were moderately soft; at times they were hard in outline.

May 11, Observer Emerson at pit

Early morning cloudy, but about 9 became clear, showing volume of smoke rising from pit increased further, with much harder outlines. Cloud rose to height of 7,500 feet more or less above pit, and whole sky to south of pit deep purple, almost black. During morning thunder of avalanches plainly audible on bluff in front of Military Camp. Capt. Perkins down during am. and brought back specimens of dust stuck to iron pipe of SE station at Halemaumau. More or less cemented, about 1.5 inches thick in thickest specimen. I visited pit at about 2.15 pm. Whole southwest fault block had been carried away but SE crags persisted as cathedral spires 300 or more feet high. Much avalanching had taken place along the W side, and rim had been carried back some 100 feet. A crack found by Capt. Perkins about 100 feet back of the rim, as it then existed, was slowly widening, sometimes an inch in 15 minutes. Earthquakes were frequent and plainly felt, often lasting several seconds, usually with fast period and decided vertical component. During the night there had been a small explosion which threw many stones onto the N and E rim. Some of the blocks weighed up to 300 lbs. Most of the material was within 100 yards of the rim, but blocks were visible on the NE side some 350 yards from the rim, measured by pacing. There was a slight hill here and these may have bounced and rolled. These stones exhibited great variation in mineral content and structure and some were distinctly crystalline; others were fine and flinty. Some contained much crystalline hematite.

O. H. Emerson

May 11, Observer Finch at pit

11 am. With W. O. Clark from Pahala. Avalanching continued all day even more vigorously than on 10th. Top of dust clouds 5 or 6 thousand feet. During night of May 10–11 there was a small explosion that blew out rock fragments, weighing 400 lbs 200 ft from rim. One 100 lb fragment found 750 feet from rim, and another block weighing 20 lb was found 900 feet back. The main deposit of rocks was on N and NE sides, though a few were found all around, with hardly any at WNW. The majority of rocks, judging from their position and bounce mark, came down nearly vertically, though some showed horizontal component. Some rocks showed zeolites, though about the only crystals noted either in rocks or dust were olivine. All the black floor from the Jan.–Feb. lava floods was gone, though the SW faulted block appeared much the same. The bottom was not seen along the western wall, though talus was observed 600–700 feet down. There was no special mark on seismogram to correlate with the explosion, judging by comparison with the May avalanche records of 1922.

May 11–12, Observer Finch, at pit

Spent night at pit. Small quakes with faint rumbling at NE solfatara 10 pm of 11th.

2.10 am of 12th, very loud noise from avalanche.

3.20 am. Numerous quakes with loud rumbling at outer parking place. Some quakes shook car. Left parking place 3.30 am. Noise like explosion puff heard at Keanakakoi 3.55 am. Quake felt Keanakakoi 4.05 am. Returned to parking place. Immediately after the earthquake spasm 3.30–3.40 am there was marked decrease in the amount of dust and height of dust column. The noise from avalanches increased. Wind at that time was very light. A daylight inspection of the rim showed little or no change from afternoon of 11th. (Watch 1 m. 40s. fast). Earthquake took place at 7 am and for a time the dense dust cloud was resumed.

May 12, Observer Finch, at Observatory

Dust clouds continued though not as intense as on the 11th.

R. H. Finch

May 12, Observer Emerson, at pit

8.45 am. Went around pit from SE to W. Conditions little changed. No further avalanching had taken place from rim, though the two cathedral spires SW had been greatly reduced in size. Avalanching generally less vigorous than on 11th. Dust clouds lighter with softer outlines. Bottom of pit at no time visible. Capt. Perkins' crack had widened only ½ inch since 3 pm yesterday. Went around to SSW. *Halemaumau SSW station* still there though dust clouds prevented going around farther to see what avalanching had taken place. Some rocks had been thrown out of pit near *Halemaumau SSW*. Hence area covered by ejecta was a zone from NW rim to parking place and a small section slightly E of *Halemaumau SSW*.

2.00 pm, walked around pit with Finch who wore goggles and BKH gas mask. I wore USA gas mask. Encountered several strong whirlwinds along S and SW sides. The masks were removed to leeward of Halemaumau but no odor whatever was detected. Noted some collapse of rim near N side at "Devil's Kitchen" and WSW, also along SW rim. Greatest recession WSW. No further changes noticeable since am. Capt. Perkins' crack had not widened at all since am. Dust to leeward plastered all rocks, solidified to a hard though friable mass. Had 1790 ash solidified as fast, the people who left their prints in it must have walked on it very shortly after it fell, not more than a very few days. Saw Fred Watzgen who was at pit shortly before 8 am yesterday. Small stones were then being thrown out of pit, with the velocity with which a man would throw stones. He heard no explosions accompanying the flying rocks.

May 13, Observer Emerson, Observatory and pit

Heavy dust clouds rose from pit at about 5.30 am, shortly after 7, about 8, at 9.35 am, and at 12.15 pm, about 1 pm. and at 2.30. This last was accompanied by a distinct report, like distant blasting, heard at Volcano Observatory.

10.15 am to shortly before noon. Visited pit. Walked around it, wearing gas mask on lee side. Apparently some further ejection of rocks along N and E side, but great series thrown out on SW. These covered a belt over 200 yds away from the pit and in places were so thick that one could not walk without stepping on them. Most of them were rather small, but they ranged up to over 200 lbs. While I was on lee side I heard a number of small explosions or avalanches. One of the boulders was still hot, temperature 50 or 60° C. Further avalanching had taken away *SSW station* and Devil's Kitchen. No noteworthy changes elsewhere. Capt. Perkins' crack on SW side widened only ½ inch in past 24 hrs. Photographed 9.35 dust cloud from cliff in front of Military Camp using panchromatic film and G filter, Bright Sun f22, ½ sec. Most of the photos with 12 inch element.

O. H. Emerson

May 13, Observer Finch, Observatory and Uwekahuna

5.40 am. Strong trades blowing at surface, above SE, higher NW, still higher SE above NW. Cloud 6000–7000 feet in height at Halemaumau.

2.30 pm. Explosion cloud. S rim observed to have fallen in at 2.35 pm. Elevation of new S rim, referred to far wall of Kilauea, 6 ft lower than old rim. (Telemeter measure from Observatory.)

4.00 pm. Explosion rocks seen high above clouds. Observed from Uwekahuna Bluff. Messrs. Boles, Belknap, Cody and others were at Halemaumàu at the beginning of this explosion. First exploision seemed near center of pit and second one from nearer east side of pit. One rock seen to go to a height of 2,500–3,000 feet. Many rocks visible above and at side of clouds. The noise of the rocks falling outside of pit plainly heard at Uwekahuna. Roar in pit heard for several seconds, prior to appearance of dust column and rocks. Explosions at intervals of 1½–2 hrs all day starting with first observed at 5.30 am. A lightning flash with its thunder was observed in 2.30 pm explosion. Good quake felt 4.48 pm at Uwekahuna and 3 more within 2 minutes. Very small explosion 4.57 pm. No rocks visible. Quakes with rumble 5.16 pm. Very perceptible quake 5.18 pm. Small explosions, no rocks, 5.20 and 5.35 pm.

6.32 pm. Explosion, very high cloud. Small explosions from time to time heard while observing at Uwekahuna during evening. Frequent quakes 10–11 pm.

May 14, Observer Finch, Uwekahuna

Spent night May 13–14 at Uwekahuna. Heavy clouds most of the night with no marked explosions. 2 quakes about 4.50 am. at one minute interval. First slow swaying motion, and second very rapid motion. Strong earthquake 5.24 am. 5.25 am. Small explosion, patter of rocks very perceptible though nearly all appeared to fall back into the pit. Considerable steam rising from N side of pit. This was the first steam observed.

9.02 am (watch slow) Heavy explosion. Dense cloud for over an hour thereafter. Ascensional rate of dust cloud at 9.25 am. 25 ft per second. An investigation of the 4 pm (May 13) explosion blocks along road over lava to Halemaumau rim, showed very few rocks compared with previous explosion that showered NE and SW rims. One 100 lb rock landed very near where road goes over 1921 lava. Another 300 lb rock landed about 1,000 ft from rim, and bounced 150 feet to its present position. During the afternoon an exploration was made of S rim of Kilauea crater. There was no evidence of new cracking. In the course of the day the avalanche clouds increased, and the amount of steam increased. There was a continuous steady moaning roar from the pit, that sounded like the roar of the Alika flow (Mauna Loa 1919) source cones heard from a distance.

3.37 pm. There was an explosion that scattered rock along W rim of Halemaumau. The roar diminished after the explosion. During the evening the roar increased and was very audible from Uwekahuna Bluff. At 10.25 pm there was an explosion again followed by a reduction of the roar. An earthquake accompanied by avalanche occurred about 10.25 pm. For 3 or 4 minutes a glow could be seen in western part of pit.

R. H. Finch

May 14, Observer Emerson, at pit

10.30 am. Visited pit, going up along road to what was left of old S hill. Rim carried away there fully 100 feet, perhaps more, and whole section to Devil's Kitchen. Apparently not much change to NE.

O. H. Emerson

May 15, Observer Finch, Uwekahuna

Spent night May 14–15 at Uwekahuna Bluff. At 3.38 am there was a strong earthquake (intensity VI) that caused avalanches from Uwekahuna Bluff as well as from Halemaumau walls. There was a tremendous dust, probably part of which was due to an explosion. The wind became easterly at about 8 am and at 9.30 am there was a terrific downpour of yellow rain, over the depressed block at Uwekahuna, so that there was a yellow cascade over the cliff.

11 am. There was an explosion that sent out great quantities of hot rocks to the SE. They were still sizzling when examined at 11.20 am. An attempt was made to see into the pit but without avail, owing to continued avalanches. During a portion of the early morning there was but little steam and no dust.

11.40 am. Another avalanche preceded by a roar plainly heard 1,200 feet from pit.

R. H. Finch

May 15, Observer Emerson, Uwekahuna and pit

8.45 am. At Uwekahuna light hiss was heard from pit. Slow SW wind blew dust toward Byron's ledge. Outline of cloud very soft.

9.45 am. Black avalanche cloud. Hiss plainly heard. Mist made visibility very poor.

10.20 am. Small explosion cloud.

10.30 am. Small avalanche.

11.10 am. Charlie Kauhi saw explosion, with many rocks thrown out over road on lava. Explosion and rock fall heard by Lovejoy at hotel.

11.20 am. Visited SE side of pit. Region much more heavily covered than before. Rocks just thrown out hot and sizzled strongly in rain. While we were at pit, small explosion cloud rose in SW part of pit, following small explosion. No rocks thrown out, so far as we could see.

2.00 pm. Slight moaning heard at Uwekahuna. Fog makes pit invisible.

2.15 pm. Slight roar, avalanche (?). Pit invisible. Shortly after, a noise sounded like explosion with rock falls.

2.28 pm. Slight quake. Moaning a little louder.

2.33 pm. Louder roar, avalanche.

2.46 pm. Louder roar. Avalanche.

2.59. pm. Light quake.

O. H. Emerson

May 15, Observer Finch, Uwekahuna and Observatory

3.00 pm. Went to Uwekahuna Bluff, O. H. Emerson having left. Noise from pit not very loud, though as time went on the noise increased. Several small shocks from time to time; very good shock at 4.37 pm. Noise quite loud from 4.30–4.40 pm.

5.44 pm. Small explosion. Good quake at 6.01 pm accompanied by roar in pit.

6.18 pm. Heavy roar.

6.26 pm. Heavy roar preceded a quake by 10 seconds. From 6.15 the roar was continuous and much like that preceding the 3.37 pm outbreak on the 14th. Very loud continuous roar from 6.35 pm on. Louder than any roar previously heard. On account of the dense fog, I left Uwekahuna and drove toward Military Camp stopping frequently to hear the roar which continued with undiminished vigor. When about half a mile from the Bluff, the noise was much fainter.

8.25–8.30 pm. Roar very loud at Observatory.

10.25 pm. Explosion. Noise diminished and was followed by only intermittent roar until sometime prior to 3 am of the 16th. Determination of depth by sound early morning of 15th made depth 1,350 plus ft. Range finder test tends to make depth greater. The factors are, rate of ascent by range-finder at Observatory, interval in seconds between noise and emergence of cloud, and distance to pit from eye and ear. The later depth estimates were fairly accurate.

R. H. Finch

May 16, Observer Emerson, at Observatory

3.15 am. Loud roar from pit, constant fume. Night clear. Cloud outline soft.

O. H. Emerson

May 16, Observer Finch, Uwekahuna

Intermittent roar at Observatory all morning (Photo).

9.00 am. Arrived *at Uwekahuna Bluff*. Loud continuous roar. Fume thin and a continuous stream of dust being emitted, though the cloud was thin. Dust falling at Uwekahuna Bluff, all the time. There was much water vapor. It was necessary to wear a hat. There was a large convection cumulus over pit at all times, base of which was about 2,000 feet above floor, sometimes much lower with very thin fume at pit rim.

9.50 am. Roar became louder. There was no change in the noise during, before nor immediately after any of the several quakes between 9 and 9.50 am.

10.20 am. Lull in the noise.

10.21 am. Perceptible quake, and noise was resumed after quake.

At Observatory and Pit

11.00 am. (Watch 6 minutes slow by Observatory clock) Rumbling. Dust cloud appeared in 1 minute; in 2½ minutes, rocks were heard falling continuously for over 7 minutes; at first the individual rocks sometimes 1–2 seconds apart.

11.27 am. Loud roar, dust cloud in 1 minute. Roar stopped after the 11.27 spasm for a few minutes. Depth of pit estimated to be over 1,700 feet, by measured ascension rate of cloud, from the sound, at the Observatory.

1.59 pm. Small explosion followed by dust cloud in about 1 minute. Heard loud roar.

2.20 pm. Good explosion with heavy cloud 2.20 pm. Small explosions at 2 minute intervals until 2.35 pm. Some rock falls heard. *Left Observatory for pit* after this explosion, with O. H. Emerson; found 2 small parallel cracks across road 2,000 feet from rim.

3.21 pm. Slight quake followed by roar and big cloud. Roar continued intermittently for 4 minutes.

3.55 pm. Very loud roar, black cloud 1 minute later.

5.00–5.02 pm. Earthquakes frequent, with heavy roaring and some rumbling from pit. Heavy clouds came out, and continued to do so, diminishing in volume only at 6 pm; an explosion.

5.15 pm. The swish became a roar and it was found to be due to mud rain. One drop of mud near Keanakakoi was fully $\frac{1}{16}$ inch high, after striking my knee. I was half-way home before the mud rain stopped.

6.11 Heavy roar from pit. Dust cloud in 1 minute.

6.42 Avalanche.

R. H. Finch

May 16, Observer Emerson, Uwekahuna

9.00–9.30 am. Loud roar audible as heard along N and NE bluff of Kilauea. Soft outline to clouds rising from pit.

10.15 am. Slight quake. Roar continuous since 9.00 am.

11.07–11.12 am. Series of gas discharges, threw rocks, at first a few big ones, then a rattle of small ones sounding like machine gun. Black cloud rose to great height. Earthquake during discharge.

Visited road at end of 1790 gravel pit SE of Halemaumau. Found small cracks cutting it just by monument, as though whole section as far as that was weakening.

O. H. Emerson

May 16–17, Observer Finch, near Pit From Algae Cliff E. side gravel spit; night of May 16–17

11.31–11.35 pm. Some small explosions.

11.41 Avalanche

11.49 Explosion

1.20 Explosion

1.27 Explosion. Continuous roar from 2.00 am of May 17th

2.28 am. Avalanche.

3.19 am. Roar louder

3.20 am. Roar much louder for a small eruption. A few red hot rocks thrown out SE of pit. 1 minute later a few came out from E part of pit. Very small eruption 3.38 am.

R. H. Finch

May 16, Observer Boles, Observatory

7.30 pm. Cloud rising full width of pit for 2,000 feet, then diffuses toward west.
7.40 pm. Roar lasting 5 sec. Dust cloud rises on E side.
8.12 pm. Roar lasting 48 sec. Dust rises on E side. Very slight NE wind.
8.46 pm. Practically clear; stars.
8.54 pm. No roar noticed. Dense cloud rises from N side and drifts to N.
8.59 pm. Roar for 30 sec. Dust rises to East side.
9.03 pm. Roar. Hot rocks thrown out 500–1000 feet to S. Lightning. Thunder.
9.07 pm. Smoke column now very high.
9.12 pm. Roar stronger. Strong NE tilt on instrument.
9.14 pm. Gravel and sand strike roof, with dust: this was the largest explosion to date.

T. Boles

May 16, Observer Lawrence, Observatory

9.20 pm. Rain of pisolites.
9.30 pm. Roar, 5 sec.
10.02 pm. Roar, 5 sec.
10.05 pm. Roar, 2 sec.
10.17 pm. Roar 20 sec. Rocks heard falling at pit.
10.21 pm. Moderate roar, 5 sec.
10.46 pm. Roar, 8 sec.
10.50 pm. Smoke increases. Drifts to SE. No roar.
10.59 pm. Roar, 18 sec.
11.05 pm. Roar, 22 sec.
11.31 pm. Roar, 13 sec. weak. Roar continued, waxing and waning, until 12.39. Then period of quiet.

Lieut. C. S. Lawrence

Geographical Conditions

The distance from Observatory to center of Halemaumau is approximately 2.3 miles southwest. Uwekahuna bluff on the W. side of Kilauea crater is approximately 1 mile from the center of Halemaumau, and the bearing of Halemaumau from it's summit station is S. 10° E. Observatory elevation (Volcano House) after the eruption is 3974 feet above sealevel, Uwekahuna 4090 feet, edge of Halemaumau 3650 feet, and the bottom of the convergent talus during the explosions inside of Halemaumau was estimated to be 1700 feet lower. The edge of Halemaumau was lowered by destruction of rim some 35 feet, and by subsidence of country 14 feet more.

It should be understood that the several observers at the Observatory were at a window commanding the pit across the Kilauea crater floor, with a Zeiss range-finder telescope and field glasses available, with mercurial barometer and barograph in the room, with a porch outside commanding the whole crater country and Mauna Loa and Mauna Kea, and with the seismograph cellar stairs in the same room so that the seismographs could be observed and readjusted at a moment's notice. The Bosch-Omori horizontal pendulums revealed tilting movements by change in the medial position of the pens north-south and east-west, and the pens were almost continuously dancing with earthquake agitation during this settling of the walls of the inner pit, and the avalanches, and the explosions. The observers learned to recognize the peculiar autograph of an explosion shake. Generally the window was wide open, so that the air-compression concussions were perceptible. From the Observatory the right side of Halemaumau is its NW side and the left is its SE side, and when directions are mentioned without other comment, there is implied the direction from the center of the pit Halemaumau. As the Observatory position is 324 feet above the Halemaumau rim, this is the first explosive eruption in history to be observed from above, and to be observed continuously minute to minute during its entire progress and decay, with levellings and triangulations made on dates before and after by the same observers (Wilson 1935).

May 17, Observer Mrs. Finch, Observatory

1.18 am. Black cloud after quiet period, but no roar.

1.32 am. Roar, 2 sec.

1.37 am. Roar, 4 sec.

2.15 am. Roar, 2 sec.

2.30 am. Black cloud, no roar.

2.39 am. Roar, 2 sec.

2.57 am. Roar, 4 sec.

3.00 am. Roar, 3 sec.

3.15 am. 4 sec. roar, very black straight cloud. One small mass of glowing rock fell in E part of pit and other rocks not glowing, could be heard falling.

3.32 am. Pisolites began to fall from enormous black cloud. Roar continuous from pit.

3.35 am. Flashes of lightning seen in cloud over pit.

3.42 am. 4 sec. roar accompanied by slight quake. By this time fan-shaped cloud had spread over almost entire sky.

3.45 am. 2 sec. roar like avalanche. Rain of pisolites much less.

3.47 am. 6 sec. roar. Pisolites cease falling.

3.54 am. 3 sec. roar. Between 4.05 and 4.18 am five roars of varying length were heard. Then a quiet period.

5.21 am. 7 sec. roar, cloud rose in NW part of pit. Pale yellow fume.

Margaret H. Finch

May 17, Observer Finch, at Halemaumau

Went up to SE rim of pit about 9.10 am with O. H. Emerson and saw a relatively flat floor with small irregularities. Steam creeping across floor in irregular fashion issuing without any appreciable pressure. SW tunnel plainly visible. Rim at SE, E and NE had gone back 200 feet. Small booming noise at 9.07 am., cloud rose rapidly at NE rim. The cracks across road at old parking place had widened, and there were new cracks across road concentric to rim all the way to pit edge. No new cracks NE. Quake with rumble 9.45 am.

10 am. Good quake with rumble and followed by rapid rise of steam cloud. Blue fume observed at NE rim, in explosive cloud. Made circuit of pit. Good view obtained at W. There is a recess in the wall N. at about the place where Devil's Kitchen was located. Cracks were found back from the rim at this recess leading off at an angle of 30° from the direction of the Kau desert crack. The extension of the SW chasm was plainly visible in the cliff on the NE side of the pit, with small dikes in the wall. Lava strata dip to a V at the SSE. Under the S there appeared to be badly cracked up lava. Quite dense steam cloud arose from pit at 11 am.

R. H. Finch

May 17, Observer Mrs. Finch, from Observatory

12.02 pm. Roar and big cloud, accompanied by slight earthquake.

12.32 pm. Roar lasted 50 sec. accompanied by sharp crashes. Very heavy black cloud, much heavier than 3.23 am.

12.35 pm. 15 explosive clouds seen to rise in 11 min. Continuous roar. Lightning flashes in cloud frequently. Loud crashes of thunder. Rocks heard to fall heavily.

12.45 pm. Pisolites begin to fall.

1.05 pm. Avalanche roar heard.

1.10 pm. Pisolites almost cease falling.

Margaret H. Finch

May 17, Observer Emerson, at Halemaumau

In afternoon visited pit again, after the great explosion shortly after noon, with Finch, L. A. Thurston and T. Dranga. Dranga and I went to the rim by road, but could see nothing on account of steam and dust. Area about there had been covered with hot dust which singed grass, was severa feet thick near the rim, and was still warm.

O. H. Emerson

May 17, Observer Finch, from Observatory

6.09 pm. Explosion.

6.10 pm. Heavy fall of rocks: 5 strokes of lightning.

6.13 pm. Heavy fall of red hot rocks. Mostly at N until 6.14 pm. Crash of very short strokes of lightning quite common in cloud above pit.

R. H. Finch

May 17, Observer Emerson, Observatory

7.30 pm. Fall of rocks heard. Lightning flashes in smoke cloud.

7.39 pm. Hiss, with thunder storm.

8.05 pm. 30 sec. roar.

8.05–9.00 pm. Thunder storm with rain.

9.00 pm. Clouds over pit thinner.

9.55 pm. Rain stopped, slight continuous hiss heard. Fume cloud thicker, tall.

10.32 pm. Small hard cloud.

10.35 pm. Large cloud, not very hard.

10.46 pm. Slight roar.

10.47 pm. Stronger roar.

O. H. Emerson

May 17,–18, Observer Dranga, Observatory

11.18 pm. Slight hiss and puff of darker cloud on west side of pit.

11.27 pm. Slight, brief roar and dark puff of cloud on East side of pit.

11.30 pm. Hissing roar and then dark dust cloud came up on east side, soon widening to width of pit, continuing 5 minutes. No rain—visibility good.

11.49 pm. Very slight steam clouds at pit.

11.51 pm. Slight roar and dust clouds on East side of pit.

May 18

12.09 am. Short roar and dust cloud on South side of pit—not very dense.

12.31 am. Short roar followed by ascending steam cloud.

12.42 am. Brief roar and puff of dust cloud. Very calm, no wind. Fine cauliflower cloud over volcano.

1.06 am. Slight thud. Only steam clouds rising from pit.

1.09 am. Roaring sound again, followed by dust clouds from both sides of pit, ceasing after 3 minutes.

1.21 am. Sudden brief roar or hiss.

1.23 am. Small dust cloud on South side of pit.

1.27 am. Hissing sound.

1.43 am. Light rain.

1.48 am. Faint sound of falling rocks. Dust cloud rising on East side of pit.

2.02 am. Thick dust cloud rising from South side.

2.04 am. Dust cloud rising East side and thick column of cloud rising out of pit. No sounds however.

2.10 am. Ordinary steam clouds again.

2.11 am. Faint roaring and small dust cloud on South side. More rain.

2.20 am. A flash—3 puffs same height. Dull red glow all over pit. Red rocks falling outside for 2½ minutes.

T. Dranga

May 18, Observer Finch, Observatory

2.25 am. Small red hot rocks shot up as high as rim of pit. Fume column very hard and rising rapidly. Lightning flashes frequent, in dust column, of very short length. Cloud aloft drifted W of Observatory, though sand and dust started to fall at 2.30 am. Dull roar continued.

3.24 am. 2 sec. roar.

3.32 am. 6 sec. roar with black cloud from SE part of pit.

3.35 am. Continued roar, lightning flashes, very short, in lower cloud above pit. Thunder heard from pit. Fume column rises rapidly and very straight. This was a small explosion.

3.43 am. Roar diminishing. The 3.33 am roar was due to rapid emission of gas without the explosive violence showing much above the rim.

4.15 am. 9 sec. roar—more sustained roaring.
4.27 am. 3 sec. roar.
4.38 am. Slight, black cloud, lightning flashes near mouth of pit.
4.40 am. Sustained roar. Sounds of falls of rock for 1½ min. Cloud very straight and slender. Very rapid rush of gas without explosive violence showing above the rim.
5.19 am. Moderate roar, small dust and steam cloud. Otherwise fume very thin.
5.22 am. Slight roar.
5.51 am. Slight roar and thin dark cloud from NE side of pit which became heavier and darker.
6.15 am. Avalanche roar and clouds from SE and NE parts of pit.
7.00 am. Cloud thicker.
7.08 am. Heavy puff of steam.
7.09 am. Roar. Even with thin fume there was a dense convection cumulus over pit.
7.12 am. Dust cloud
7.24 am. Avalanche roar.
7.38 am. Red dust cloud from N side of pit.
7.48 am. Dense dust cloud from N. Slight roar.
7.50 am. Roar increased. Dust cloud very heavy as viewed from NE. No evidence of any explosion. Ascensional rate of cloud indicated that it was due to avalanches, in all probability. The seismogram, however, suggested a small explosion.

R. H. Finch

Great Crisis of May 18, Observer Emerson, from Observatory

8.20 am. High pitched roar.
9.00 am. Large avalanche.
9.07 am. Large avalanche SE, some N.
9.11 am. Short roar.
9.30 am. Slight roar occasionally audible. Cloud rising, contains much steam, some dust.
9.45 am. Steam rising, rapidly from N end of pit.
9.50 am. Short roar, clouds rise moderately fast.
9.53 am. Speed of clouds materially increased.
9.55 am. 5 sec. roar, plainly audible, steam rising minute later, no dust.
9.57 am. Slight quake on seismograph, some soft dust clouds.
9.59 am. Slight roar.
10.00 am. Roar and dust cloud N. avalanche?
10.09 am. Steam cloud rising rapidly from N and NW part of pit.
10.12 am. Cloud rising fast.
10.17 am. Decidedly felt quake, first warning of coming explosion.
10.19 am. Second quake, slight.
10.34 am. Rumble and slight quake, house rattled.
10.36 am. Rumble.
10.37 am. Rumble with quake.
10.45 am. Small cauliflower.
10.54 am. Roar, 10 sec. Slight dust cloud to SE.
11.01 am. Sharp quake.
11.02 am. Roar, explosion cloud. No rocks observed.
11.07 am. Main explosion with tremendous dust cloud. Rocks.
11.09 am. Second explosion with rocks. Plastered area to NE with hot sand. Sand sent several hundred yards to NE.
11.12 am. Third explosion with rocks, much smaller.
11.20 am. Loud roar, constant. Fall of pisolites.
11.21 am. Small explosion to SE.
11.55 am. Small explosion with fall of rocks, followed by some thunder.
12.15 pm. Hard black cauliflower still rising; mist then descended making pit invisible.

O. H. Emerson

Great Crisis of May 18, Observer Finch Near Halemaumau, by Algae Cliff, E. Side of Sand Spit.

10.36 am. With L. A. Thurston and W. O. Clark of Pahala. Large puffs of steam; rumbling, earthquake. Went to sand spit above Algae and sat down on a boulder which had been ejected at 12.30 pm. May 17. Numerous quakes and rumbling. Sent T. Dranga Jr. to get Thurston who was with Carlsmiths. A wave of increased air pressure that decidedly hurt my head, was felt at 11.09 am. Jumped and exclaimed, "Here comes a terrible one." The air pressure was felt several seconds before rocks appeared and two or three seconds before the explosion cloud cleared the rim. Started to take picture but saw rocks of great dimensions high in the air headed toward our locality. Ran to cliff and slid down a wash. A rock, judging from its air appearance to have weighed over 300 lbs cleared the cliff and landed on 1921 lava. Left Thurston, Clark and ladies of Carlsmith party, on cliff. O. Emerson in the afternoon reported a 10-ton rock on airplane landing-field, found while searching for possible killed or wounded soldiers. Two men were seen on rim of pit a short time before 11.09 am. explosion. T. A. Dranga Sr. came across crater floor but said that Mr. Truman Taylor of Pahala, who was with him on the way up to crater, had left him 10 minutes before the explosion. Went back to find missing man with Clark, Dranga Jr. and Dranga Sr. Taylor was discovered with legs crushed by fallen bowlders about 125 feet from old parking place. Dranga Sr. started to get car seat, to use as stretcher, when another explosion came. Dranga Jr. and I carried Taylor to road where he was put into car.* 11.54 am. explosion quite mild.

R. H. Finch

Great Crisis of May 18, Observer Mrs. Finch. Near Keanakakoi, sitting on ground.

10.16 am. 3 quakes felt within 5 minutes. Between 10.30 and 11.00 am quakes were decidedly sharper and of very rapid vibration. Roar from pit almost continuous.

11.09 am. Big explosion cloud rose from center of pit, followed by others to NE of pit. Enormous rocks seen about 3,000 feet in air and slightly in advance of explosion cloud bearing them. Rocks thrown great distance toward Keanakakoi and Landing Field. NE part of pit practically clear.

11.14 am. Second explosion, slighter. Rocks thrown out.

11.20 am. Rain of pisolites as large as a pea.

11.54 am. Explosion cloud rose from NE part of pit, followed by others in central part. Rocks thrown out, chiefly on NE and E. Rain of pisolites continued until after we arrived at Observatory.

Margaret H. Finch

May 18, Observer Finch at Observatory

Then came a torrential downpour, 2 inches of rain in 30 minutes at Observatory. Intense electrical storm followed, even touching a metallic automobile produced a shock. 21 telegraph poles were destroyed by lightning in a line about 4 miles toward Hilo from volcano. There was fearful and wonderful visible lightning. Large insulated bodies like a motor car acquired heavy charges of electricity.

R. H. Finch

Afternoon of Critical Day, Observer Emerson May 18 at Halemaumau

2.00–3.00 pm. Visited E and N rim of pit with Capt. Perkins and some enlisted men on party looking for two men who were believed to have been lost during explosion before noon; much sand covered area near pit, probably up to three feet thick near rim, thinning down farther back to a few inches by horse corral. A blast had plastered section to NE of pit with small rocks to a distance of 700 yds or more from pit. Some large rocks must have been fully 800 yards distant. Appeared to be some fresh cracks extending to NE of pit toward N end of Byron's ledge. This series was not anywhere nearly as well developed as the SW series, as latter was observed on day before, (Bulletin, May 1924, p. 43) and did not yet extend to any great distance from pit.

O. H. Emerson

May 18, Observer Burdick, Observatory

1.00 pm. Pit not visible.

1.19 pm. Small explosion.

1.29 pm. Heavy cloud like the end of an explosion.

1.34 pm. Small explosions.

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*Taylor died that night at Hilo Hospital.

2.00 pm. Heavy cloud.
2.01 pm, roar like thunder accompanied by compressional wave.
2.14 pm. Roar.
2.37 pm. Cloudy.
2.50 pm. Clear, low down. Heavy clouds in center.
3.05 pm. Heavy roar.
3.08 pm. Misting, pit indistinct.
3.25 pm. Puff of air pressure, followed by thunder. Recorded on barograph.
3.40 pm. Big dust cloud.
3.56 pm. Heavy roar.
4.25 pm. Dust cloud.
4.32 pm. Large dust cloud.
4.35 pm. Very large cloud, rapid movement.
4.52 pm. Dust cloud.
5.05 pm. Light red cloud.
5.15 pm. Dust cloud.
6.25 pm. to 6.35 pm. Crater clear except for light steam clouds of gradually increasing density.
6.40 pm. Black cloud.

Allen Burdick

May 18, Observer Finch, Observatory

7.13½ pm. Roar.
7.14 pm. Rocks heard falling.
7.17 pm. Still going strong, very heavy to SE.

7.18 pm. Rocks landing on Uwekahuna Bluff, lower ledge, and still glowing. Most rocks at N. Rocks seen over 3000 feet high. Barrage of red hot rocks progressed northeast towards Observatory in 500-foot leap vertically; few fell farther on this side than 2500 to 3000 feet from pit rim horizontally.

7.19 pm. Dying down.

7.22 pm. Glow still shows from hot rocks. Dull glow from pit. Ground around pit illuminated by hot rocks. Ground at SE very heavily bombarded. Large rock to E about 4000 ft. judging by diameter of pit. One rock toward Military Camp about 5,000 feet from rim. Barrage of rock probably equal to 12.30 pm eruption of 17th.

May 18, Observer Finch, Observatory

7.57 pm. Roar, rocks landing, lightning.
7.57½ pm. Dying down.
7.58 pm. Starting up again, rocks seen, heavy cloud.
7.59 pm. Still continuing; quake. Rocks still glowing.
8.00 pm. Dying down.
8.00½ pm. Starting up again.
8.01 pm. Increasing.
8.01½ pm. Dying down, rocks still glow.
8.02½ pm. Thunder and lightning, quake.
8.03½ pm. Heavy roar, probably ash fall.
8.05 pm. Continued roar.
8.05½ pm. Roar increasing.
8.06½ pm. Roar dying down.
8.07½ pm. Roar continuing.
8.08½ pm. Roar increasing, heavy thunder.
8.10 pm. Intensely black cloud over pit.
8.12 pm. Cloud spreading, blacker.
8.20 pm. Continuous roar, fall of pisolites. Mauna Loa clear, whole summit snow-covered.
8.25 pm. Roar, avalanche.
8.30 pm. Roar, avalanche.
8.48 pm. Roar, avalanche or gas hiss. White cloud, however, accompanied it.
8.50 pm. Continuous roar until 8.55 pm.

R. H. Finch

May 18, Observer Mrs. Finch, Observatory

9.15 pm. Roar, 50 sec., cloud from NE part pit.

9.45 pm. Quiet, white cloud rising.

10.26 pm. Roar, 10 sec.

10.46 pm. Weak roar.

11.03 pm. Weak roar and avalanche cloud seen.

11.08 pm. Moderate roar, short, followed by whitish cloud (steam?) in center of pit, which came in sight almost immediately after roar, unlike avalanche clouds which rise more slowly.

11.11 pm. Moderate prolonged roar, no white cloud.

Margaret H. Finch

May 18–19, Observer Finch, Observatory

11.14 pm. Heavy roar. The so-called "bombs bursting with white light" were short strokes of lightning. The thunder following was as sharp as the crack of a pistol.

11.20 pm. Cloud very heavy.

11.49 pm. More whitish clouds appeared in center of cloud above rim—no noise.

11.52 pm. Much more white cloud.

May 19

12.32 am. Loud roar from pit.

12.37 am. Loud roar—white cloud.

12.43 am. Mild roar, probably an avalanche.

12.52 am. Avalanche roar, loud, no quake.

2.05 am. Pit quiet.

2.30 am. Pit quiet, left for bed.

2.57 am. Quake felt at locality called "29 miles," one mile from Kilauea northeast.

3.58 am. Several quakes.

4.00 am. Explosion, very few red hot rocks thrown out.

4.02 am. Heavy thunder. Pit quiet all morning, though steam cloud rising rapidly from E part of pit. Sand deposit very heavy on Kilauea floor southeast of pit; along NE and N rim one sheet of sand some distance out at the N.

R. H. Finch

May 19, Observer Burdick, Observatory

10.04 am. Heavy steam cloud left (southeast) side of pit, dust cloud at right side, clear between.

10.08 am. Roar from avalanche, dust.

10.30 am. Avalanche.

10.34 am. Ash cloud to right of pit, steam cloud to left.

10.49 am. Heavy quake, steam cloud rising from pit.

10.50 am. Heavy dust cloud.

Allen Burdick

May 19, Observer Mrs. Finch, Observatory

11.05 am. Moderate steam cloud continues rising over entire S part of pit.

11.06 am. Moderate dust cloud in NE part of pit.

11.11 am. Moderate steam cloud in central part of pit.

11.15 am. More heavy steam clouds.

11.16 am. Heavier steam cloud still.

11.17 am. Heavier steam cloud spreads over entire pit.

11.24 am. Steam continues, slightly weaker.

11.36 am. Steam cloud in E pit—moderately heavy.

11.44 am. Heavy dust cloud.

Margaret H. Finch

May 19, Observer Finch, Observatory

11.50 am. Dense dust over 6,000 ft high. Small explosions, continuous small quakes registered.

11.51 am. Lightning flash in cloud near rim of pit. Thunder several times. Dense dust volutes continue.

11.53 am. Lightning nearly continuous with short sharp cracks.

11.54 am. Heavy roar probably due to avalanche or small explosion. Pit obscured due to descending dust to the E and NE.

11.55 am. Clouds rising more rapidly.

12.00 noon Dense dust volutes continue. All clouds probably due to avalanche dust, perhaps with gas rush. Viewed from Observatory, the rim of pit was 1700 feet above its floor; the volutes seen rising did not distinctly manifest explosion characters.

12.12 pm. Occasional lightning flashes to right and left of smoke column.

R. H. Finch

May 19, Observer Durning, Uwekahuna

Rocks falling on left of crater viewed from Uwekahuna, two rather heavy falls. This was a distinct explosion, confirmed as such by the seismograms. After quiet, heavy rock fall heard from side opposite cliff.

12.29 pm. Heavy dust cloud.

12.46 pm. Steam cloud.

12.59 pm. Heavy steam cloud.

1.10 pm. Heavy steam cloud.

1.16 pm. Dust and steam cloud. (Steam and dust clouds, with occasional roars until 5.38 pm.)

F. Durning

May 19, Observer Finch, Observatory

5.39 pm. Start of explosion.

5.40 pm. Lightning, explosion from S side of pit, alternating from different portions. Sounds of falling rocks. Explosion from SE side. Rocks seen to fall. Most explosions small. Usual short lightning at base of cloud.

5.41 pm. Larger explosion.

5.43 pm. Heavier explosion. Larger streaks of lightning. Avalanche from NE rim. Lightning higher up in cloud.

5.44 pm. Quieted.

5.45 pm. Lightning continues occasionally.

5.48 pm. Sharp lightning in cloud around column.

5.51 pm. New explosion or gas rush. Short flashes of lightning in cloud. Heavy avalanche clouds to S and E. Most of dust cloud descended in Kau Desert.

5.53 pm. Avalanche cloud at N.*

R. H. Finch

May 19, Observer Emerson, Observatory

6.47 pm. Explosion with loud roar of falling rocks, but mostly not thrown very far.

6.52 pm. End of fall of rocks. Some thunder.

7.15 pm. Slight roar, fall of pisolites.

7.24 pm. Slight quake.

7.27 pm. Slight quake.

O. H. Emerson

May 19, Observer Durning, Observatory

7.30 pm. Small explosion making visible a few hot rocks.

7.44 pm. Lightning.

7.45 pm. Continued lightning.

7.47 pm. Continued lightning.

7.47½ pm. Roar.

7.49 pm. Glowing rock, hardly seen through fog on east side.

7.52 pm. Earthquake, slight.

7.53½ pm. Earthquake, very feeble.

7.55½ pm. Harmonic tremor, pronounced.

7.57 pm. Low visibility over crater. Cloud over pit, some lightning.

7.58 pm. Slight earthquake. Heavy dust cloud.

7.59 pm. Slight earthquake.

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* True directions from center of pit.

8.01 pm. Lightning flashes, mist is clearing from crater.

8.01½ pm. Heavy cloud drifting to the east. Probably dust.

8.03 pm. Dense cloud pouring out of pit.

8.04 pm. Marked harmonic tremors.

8.05½ pm. Steam cloud in moon light.

8.06½ pm. Slight earthquake. Steam cloud rising rapidly.

8.07 pm. Slight earthquake, feeble.

8.08½ pm. Steam continues heavy, apparently carrying ash.

8.09½ pm. Feeble earthquake, roar in pit.

8.10 pm. Increase of dust column.

8.12 pm. Earthquake, rapid rising of cloud.

8.12½ pm. Moderate earthquake.

8.13 pm. Greatest volume of cloud from NW.

8.14½ pm. Heavy dust, low hanging clouds.

8.18 pm. Roar.

8.20 pm. Hot (glowing) stones, earthquake.

8.20½ pm. Roar increasing.

8.20¾ pm. Earthquake feeble.

8.21½ pm. Earthquake, slight.

8.22 pm. Roar.

8.23 pm. Dust cloud, perceptibly thicker.

8.23½ pm. Slight quake.

8.24 pm. Pronounced west tilt all evening.

8.25½ pm. Feeble quake.

8.26 pm. Thunder over pit, lightning visible.

8.27 pm. Slight quake.

8.29½ pm. Heavy quake on north-south seismogram.

8.30 pm. Quake continues strong, tilt to N and W.

8.30¼ pm. Slight quake.

8.30½ pm. Feeble quake.

8.33 pm. Heavy quake, lunar rainbow to west of pit.

8.34 pm. Cloud rising above pit.

8.34¼ pm. Slight quake.

8.34½ pm. Roar.

8.35½ pm. Cloud increasing, rising high.

8.38 pm. Lightning over pit.

8.38½ pm. Lightning low NE side.

8.40 pm. Strong harmonic tremor.

8.41 pm. Lightning over pit.

8.42½ pm. Lightning flash.

8.49 pm. Slight quake.

8.50 pm. Low cloud.

9.04 pm. Roar, short duration.

9.06 pm. Mist drifting into crater.

9.11 pm. Steam cloud.

9.12–13 pm. Steady tremor of harmonic nature.

9.22 pm. Dust cloud, continuing strong.

9.23½ pm. Heavy quake, N-S component dismantled, felt at Glenwood strongly.

9.24½ pm. Roar, continues growing stronger, small explosion.

9.25½ pm. Roar stops.

9.26 pm. Mist hanging low, shutting out some of pit rim.

9.29 pm. Slight roar, continues and growing stronger.

9.30 pm. Heavy dust, hot (glow) rocks on N side.

9.31 pm. Rapid rise of dust cloud, moderate explosion.

9.31½ pm. Small amount hot rocks N side.
9.35 pm. Lightning.
9.35½ pm. Heavy quake, roar, dust cloud rising rapidly, roar continues.
9.36 pm. Roar stronger, dust cloud very heavy.
9.37 pm. Explosion in pit.
9.38 pm. Action slowing up.
9.39 pm. Dust cloud very high, roar growing very strong.
9.40 pm. Roar dying down.
9.40½ pm. Dense cloud rising from pit.
9.41 pm. Heavy cloud of dust.
9.42 pm. Dust cloud continues heavy.
9.43 pm. Lightning high over pit.
9.45 pm. Very high dust cloud, small explosion.
9.46½ pm. Lightning in dust cloud.
9.47 pm. Lightning low down.
9.50 pm. Lightning continues.
9.51 pm. Rocks dropping back into pit.
9.53 pm. Lightning to right. Cloud not rising very high. West wind aloft.

F. Durning

May 19–20, Observer Finch, Observatory
10.21 pm. Roaring at pit.
10.24 pm. Heavy roar at pit.
10.24½ pm. Slight quake, roar louder.
10.25½ pm. Slight quake.
10.30 pm. Roar in pit, heavy cloud rising.
10.32½ pm. Sound of rocks falling.
10.35 pm. Slight roar.
10.38 pm. Slight quake.
10.40 pm. Avalanche NW.
10.43 pm. Heavy dust cloud from N.
10.45 pm. Heavy dust cloud from NW.
10.53 pm. Heavy dust cloud from N rising rapidly.
10.55 pm. Slight roar, heavy cloud N.
10.58 pm. Very feeble earthquake.
11.01½ pm. Large steam cloud rising.
11.05 pm. Fume very light.
11.08 pm. Steam cloud.
11.21 pm. Roar, avalanche.
11.22 pm. Roar continues, heavy dust cloud.
11.23 pm. Slight quake and dense dust cloud NW.
11.24 pm. Very heavy dust cloud.
11.25 pm. Slight roar, avalanche.
11.27 pm. Spurt of dust on E side.
11.28 pm. Fog drifting into crater.
11.30½ pm. Avalanche NW side, spurt of dust.
11.33 pm. Spurt of steam and dust NW side.
11.36 pm. Heavy spurt of steam and dust NW side.
11.43 pm. Slight roar.
11.44 pm. Dust and steam spurt NW side.
11.45 pm. Wind ESE, dust drifting toward Mauna Loa.
11.47 pm. Avalanche NNW.
11.56 pm. Feeble quake, pit obscured by mist.
May 20

12.05 am. Heavy roar at pit.

12.07 am. Roar, harmonic tremor.

10.10 am. Fog obscuring pit.

12.16 am. Pronounced barometric disturbance; tremor over 4 min.

12.20 am. Slight tremor.

12.27 am. Very feeble quake, Pit obscured by mist.

12.30½ am. Slight quake.

12.38 am. Slight quake.

12.40½ am. Pit obscured by mist.

12.44 am. Slight roar.

12.46½ am. Slight quake. Explosion.

12.46¾ am. Continuing.

12.47¼ am. Still continuing.

12.47½ am. Heavy quake.

12.47¾ am. Dismantled instrument.

12.51¾ am. Strong east tilt.

1.31 am. Roar.

1.45 am. Pit visible. Very little cloud to only a small height. Low cloud probably due both to diminished heat and steam from pit, and to higher wind velocity.

1.50 am. Pit obscured.

2.12 am. Heavy steam cloud not very high with top leaning over Kau desert.

2.52 am. Roar, followed by heavy cloud N side of pit.

2.55 am. Roar.

2.57 am. Loud roar.

2.59 am. Lightning flash in cloud.

3.00 am. Loud roar.

3.38 am. Heavy cloud over pit.

3.40 am. Heavy quake. Instrument dismantled.

3.46 am. Pit invisible on account of clouds and mist.

3.48 am. Heavy dust cloud visible.

R. H. Finch

May 20, Observer Durning, Observatory

3.56 am. Base of dust cloud to be seen under fog, quite dense.

4.02 am. Heavy earthquake. Instrument dismantled.

4.03 am. Very heavy spurt of dust.

4.07 am. Dust cloud still very heavy.

4.10 am. Some steam NW side.

4.12 am. Not much dust, steam cloud.

4.14 am. Heavy spurt of dust.

4.24 am. Dust cloud still heavy and drifting very low on SW side pit.

4.28 am. Steady rise of dust cloud on S and SE, with spurting on NW side.

4.31 am. Slight quake, dust spurt to NW.

4.35 am. Pit obscured by fog.

4.39 am. Spurting dust at NW side.

4.42 am. Slight tremor continuing 1½ min., followed by quake.

F. Durning

May 20, Observer Finch, Observatory

4.44 am. Tremor continues.

4.45 am. Quake.

4.47 am. Quake.

4.48 am. Quake. No noticeable change in pit cloud.

4.49 am. Considerable white fume from NE.

4.51 am. Tremor still strong.

4.55 am. DENSE CLOUD from center of pit followed by dust and steam cloud all over pit, gradually lessened. Explosion.

5.05 am. Avalanche cloud from NE.

R. H. Finch

May 20, Observer Emerson, Observatory

5.10 am. Large volume of steam rising from pit constantly.
5.26 am. Moderate quake. East-west seismograph dismantled.
5.50 am. Cloud soft, no sharp outlines.
6.00 am. Avalanche cloud NE.
6.09 am. Small avalanche cloud N.
6.12 am. Slight quake.
6.15 am. Big avalanche cloud E.
6.17 am. Moderate quake.
6.23 am. Moderate quake.
6.39 am. Avalanche NE.

O. H. Emerson

May 20, Observer Finch, Observatory

7.00 am. Avalanche from the N.
7.01 am. Heavy steam cloud NE.
7.03 am. Very heavy quake, drum not on.
7.03½ am. Very heavy quake, drum not on.
7.07 am. Pit clear except for steam NE.
7.10 am. Heavy steam cloud SE.
7.22 am. Heavy dust and steam cloud SE.
7.39 am. Small explosion starting at SE side, spread to N very quickly.
7.45 am. Heavy dust cloud in NW.
7.50 am. Dust cloud increasing.
7.55 am. Dust cloud diminishing.
7.58 am. Dense cloud NE side pit.
8.01 am. Dense cloud NE side pit.
8.05 am. Dense cloud ENE side pit.
8.06 am. Avalanche from N. Rapid rise of cloud NE.
8.08 am. Rapid rise from NE continues.
8.15 am. Dense cloud continues.
8.21 am. Dense cloud SE.
8.23 am. Dense cloud NE.
8.24 am. Roaring.
8.58 am. Dense cloud continues with most rapid ascensional rate at NE.
9.15 am. Continued rapid rise of dust cloud.
9.40 am. Rapid rise of dust cloud continues with most rapid ascensional rate at NE.

R. H. Finch

May 20, Observer Emerson, Observatory

10.13 am. Hard cloud, E side.
10.24 am. Small avalanche cloud to W.

O. H. Emerson

May 20, Observer Finch, Observatory

11.45 am. Heavy puff of steam rose from most of pit.

12.27 pm. Rapid rise of steam from NE continues. The heaviest continuous steam cloud during the eruption has been rising all forenoon.

12.47 pm. Very rapid rise of steam ENE.
12.49 pm. Eruption. First ENE, second to the N, rocks to N short distance.
12.50 pm. More explosion. Heavy roar.
12.52 pm. Small explosion.
12.58 pm. Rapid rise of dense dust clouds continues.

12.59 pm. Heavy descent of dust Kau desert. Cloud easily over 2 miles high, probably 4 or 5 miles; 2 miles if drifting NE, 4 miles if straight up.

1.02 pm. Rate of ascent of dust that of small explosion, with rolling over rim of pit at times. Especially from NE part of pit. High pressure probably continues for some time after explosion.

1.54 pm. Moderate earthquake. Heavy mist still shuts out view of pit.

R. H. Finch

May 20, Observer Durning, Observatory

2.35 pm. Fog lifted for minute, only light steam cloud over pit.

2.40 pm. Moderate quake, dismantled both pens of instrument: origin more distant than Halemaumau, thought to be in Kau.

2.42 pm. Spurts steam and dust from pit.

2.53 pm. Heavy steam cloud, very little dust.

3.25 pm. Steam cloud slowly rising, or dust.

3.25½ pm. Heavy spurts steam and dust.

3.27 pm. Heavy spurts steam over entire pit, red dust on NNW.

3.28 pm. Avalanche NW side.

3.30 pm. Avalanche NW. Heavy steam and dust cloud in very rapid rise over entire pit.

3.36 pm. Red dust cloud on NNW.

3.40 pm. Steam, light dust over entire pit.

3.45 pm. Steady rise of steam—no dust.

3.50 pm. Steady rise of steam—no dust.

3.55 pm. Steam a little heavier on NW side.

4.05 pm. Small dust cloud NW.

4.25 pm. Pronounced tremor, continuing some time.

4.31½ pm. Dust cloud continues very heavy, rapid rise with spurting on N and E.

4.37 pm. Lightning south pit in dust cloud.

4.38 pm. Feeble earthquake.

4.38½ pm. Lightning flash over pit.

4.40 pm. Spurt of rocks and ash on E side.

4.40:40 pm. Rock blast on NE side.

4.42½ pm. Continued lightning flashes.

4.44 pm. Mist is lifting.

4.44½ pm. Dust cloud very hard and rocks west end.

4.45 pm. Spurt of heavy ash and rocks west end.

4.46 pm. Dust cloud is drifting SSE.

4.46½ pm. Mist again over pit.

4.49 pm. Dust cloud rising more slowly.

4.56½ pm. Explosive burst over entire pit, dust and steam, no rocks to be seen.

4.57 pm. Mist at pit.

5.16 pm. Slight earthquake.

5.18 pm. Feeble earthquake.

5.19½ pm. Slight earthquake.

5.20–5.24 pm. West tilt, steady tremor.

5.26 pm. Moderate quake.

5.27 pm. Very heavy dust cloud.

5.28 pm. Spurting dust cloud over entire pit.

5.31 pm. Mist entirely obscures pit.

5.34 pm. Tremor continues steady with swarm of very feeble shocks, and tilt still holds to the west. (Explosion observed 5.34 pm., from near Keanakakoi by W. J. Belknap, on SE side of pit.)

5.39 pm. Mist rising, dust cloud seems to be soft and heavy with steam.

5.56 pm. Heavy steam cloud, not very much dust.

7.00 pm. Mist is lighter over pit.

7.05 pm. Cloud over pit mostly steam.

7.10½ pm. Sudden spurt of steam over entire pit.

7.20 pm. O. H. Emerson, Lieut. Lawrence and one enlisted man left to spend night at Half-Way House in Kau.

7.34 pm. Light fog drifting in from N.

7.40 pm. Pit obscured by mist.

7.44 pm. Dust cloud rising rapidly over pit.

7.59 pm. Sky is clear in NE.

8.12 pm. Slight roar, avalanche NNW, dust cloud quite heavy, but rising slowly.

8.25 pm. Seismograph shows constant harmonic tremor and some very feeble earthquakes.

8.46 pm. Heavy shock, dismantles pen.

8.48 pm. Heavy dust cloud from pit.

8.54 pm. Dust cloud very high.

8.55 pm. Dust cloud continues to rise very fast—blast of dust and ash on NW.

9.05 pm. Dust cloud still heavy—no explosion.

9.12 pm. Dust cloud still very dense. Wind carrying ash south over Kau desert.

9.20 pm. More steam in cloud, no spurting.

9.34 pm. Steam cloud over pit.

9.50 pm. Heavy spurting, dust cloud.

9.55 pm. Dust cloud continues heavy but rising slowly.

10.3.30 pm. Avalanche on NW side.

10.4.30 pm. Heavy spurt of steam east side.

10.15 pm. Slowly rising steam cloud.

10.30 pm. Slowly rising steam cloud.

10.45 pm. Slowly rising steam cloud.

11.00 pm. Very heavy steam cloud with some dust on NW side.

11.15 pm. Heavy steam, very little dust.

11.30 pm. Heavy steam, very little dust.

11.45 pm. Heavy steam, very little dust.

F. Durning

May 21, Observer Finch, Observatory

12.44 am. Avalanche cloud from the N added to the usual heavy steam cloud which is now considerably taller. Small perceptible quakes frequent.

1.00 am. Wind ENE.

1.15 am. Heavy steam cloud NE.

1.24 am. Moderate quake, dust cloud N.

2.00 am. The quakes which have been frequent since midnight, while mostly of small amplitude, are easily perceptible and make the observatory building creak.

2.16 am. Rumble at pit followed by heavy quake and tremendous avalanches. Both components dismantled.

2.17 am. Dense dust cloud, accompanied by explosions which were mild; no lightning was observed, thunder was heard. No hot glow rocks seen.

2.30 am. Dust cloud still heavy.

2.37 am. Roar at pit.

2.45 am. Dust falling in Kau desert, and heavy steam clouds rising from pit.

3.30 am. Heavy dust and steam cloud.

4.00 am. Very few quakes since 2.16 am.

4.20 am. Two distinct steam columns, one at usual place NE, and another S of pit.

4.25 am. Heavy steam cloud.

4.47 am. Sharp earthquake shock. Strong E-W motion felt. E-W component dismantled, and vertical movement felt.

4.58 am. Avalanche from the N.

5.10 am. No crack could be found along the road in immediate vicinity of Volcano House, to account for the peculiarity of the 4.47 quake, as being immediately local.

5.34 am. Heavy steam jet from NE.

5.46 am. Heavy steam jet from NE.

5.50 am. Photo 6½ by 8½. Mostly NE wind. Cloud 2 or 3 mi. high.

5.53 am. Heavy dust cloud NE and N.

5.58 am. Heavy dust cloud NE and N continues.

6.00 am. Cracked block observed with field glasses along N rim. Crack appeared to be 30–35 feet back from rim.

6.14 am. Steam rising in puff from NE heavier.

6.46 am. Dust cloud N, steam puff.

6.49 am. Dense cloud general, all parts of pit of dirty gray color, rising more rapidly even than the steam puffs.

6.53 am. Dense clouds continue to rise NE. Occasional small red avalanche cloud elsewhere.

7.01.am. Gray clouds rising NE and red clouds N.

7.09 am. Heavy puff gray cloud SE, red clouds continue at N.

7.21 am. Rapid rise of gray clouds SE.

7.24 am. Instrument dismantled, earthquake.

7.25 am. Red dust cloud N.

7.34 am. Dense voluted dust cloud rising rapidly. Small explosion though no rocks seen.

7.43 am. Dense dust volutes continue, though ascensional rate decreased.

7.54 am. Hard outline of cloud continues at SE, soft at N.

7.56 am. Red avalanche cloud N.

8.00 am. Red avalanche cloud N. Cloud from SE diminishing.

8.18 am. Rapid rise of red cloud N, and gray cloud SE, as 2 columns, with blank between.

8.24 am. Dense dust cloud N, red.

8.26 am. Less dust on E, but continuous rise of heavy red dust cloud on NW.

8.33 am. Dense red dust volutes from N. The two column arrangement persists. Photo of two-colored dust cloud.

8.48 am. Dense hard dust clouds all over pit, probably small explosion, or gas rush.

8.50 am. Dense dust clouds diminish. Seismograph indicates explosion.

8.52 am. Another small explosion rush of dust from all over pit. Found N-S component dismantled when inspected 8.55 am. Nearly continuous tremor.

8.59 am. Cloud softening.

9.02 am. Very little cloud from N side of pit. Heavy fall of dust in Kau desert.

9.18 am. Rapid rise of dust continuous at S side of pit. N side rather quiet.

R. H. Finch

Half Way House Trip, Observer Emerson, night of May 20–21

Party consisting of O. H. Emerson from Observatory, Capt. Dewar, Lieut, Lawrence, Mr. English, Mr. Wintels from Military Camp. Spent night on porch of Half Way House. Felt slight quake about 8 pm. Had big dust storm about 3.30 am. corresponding to the falling dust, seen as reported above from Observatory, at 2.45 am. and thereafter. About 7.00 am. visited Mauna Iki. No sign of activity between Kilauea and Kamakaia. Some hot cracks on top of Mauna Iki, T. about 75° C. While at Mauna Iki, dust cloud rose above Halemaumau till it subtended angle whose tangent is 0.35 (19°), 5 minutes after explosion. Walked to old lava beyond Mauna Iki and looking with field glasses could see no new cracks.

O. H. Emerson

May 21, Observer Durning, Observatory

9.20 am. Heavy blocks on N and SE side.

9.44.30 am. Heavy avalanche on NW.

9.50 am. Heavy spurt of black dust cloud.

9.52 am. Avalanche on N.

9.53 am. Heavy explosive cloud from entire pit.

Mr. Emerson returned from Kau.

9.58 am. Avalanche on NW side.

9.59 am. Explosive cloud heavy on SE side.

10.01 am. Puffing steam cloud over entire pit.

10.02 am. Mr. Finch reports pit rim 600 feet farther back at S side than on May 5.

10.05 am. Continuous avalanching on NW.
10.06 am. Continuous avalanching on NW.
10.20 am. Heavy avalanche on NW side, spurting steam and dust S and E.
10.25 am. Red dust continues to rise on NW of pit.
10.30 am. Steam still rising rapidly on E side.
10.31 am. Pit obscured by mist.
10.55 am. Mr. Finch reports numerous cracks concentric with pit seen from bluff.
11.00 am. Occasional glimpses of pit possible.

F. Durning

May 21, Observer Finch, Observatory

12.00 noon. Avalanche N side. Steam rising slowly. The avalanching during this noon and forenoon has been more pronounced than at any other time.

12.10 pm. Avalanche N heavy cloud rose somewhat slowly from entire pit.

12.49 pm. Slight quake felt.

12.55 pm. Avalanche from N following 2 earthquakes; first dismantled N-S, second dismantled E-W components. Heavy gray clouds S part of pit.

R. H. Finch

May 21, Observer Emerson, Observatory

1.04 pm. Tremendous S tilt.
1.20 pm. Avalanche N.
1.25 pm. Moderate quake.
1.30 pm. Big dust cloud from SE area.
1.53 pm. Slight quake felt.
2.04 pm. Slight quake felt.
2.05 pm. Hard cloud from SE.
2.09 pm. Slight quake.
2.12 pm. Slight roar.
2.15 pm. Dust and steam cloud SE.
2.17 pm. Avalanche W.
2.30 pm. 10-second roar.
2.31 pm. Dust and steam clouds W.

O. H. Emerson

May 21, Observer Durning, Observatory

2.57 pm. Avalanche on NW, spurts of steam and dust on E side.
3.10 pm. Avalanche on NW.
3.15 pm. Heavy spurt of dust starts on E side.
5.18.30 pm. Very heavy spurt of dust on E side.
3.21 pm. Dust and steam cloud rising still on E side.
3.25 pm. Avalanche on N side.
3.30 pm. Small avalanche NW side.
3.38 pm. Small avalanche N side.
3.40 pm. Avalanche on NW.

3.49 pm. Moderately strong earthquake, followed by burst of dust starting on NW side; marked south tilt. Dismantled NS component.

3.54 pm. Dust still heavy on NW.
3.55 pm. Dust generally heavy over entire pit.
3.56 pm. Avalanche on N side.
3.57 pm. Strong red dust cloud on north.
3.59.30 pm. Strong spurt of dust on E side.
4.01 pm. Avalanche on NW, less dust over E side, slow rising steam.
4.11 pm. Avalanche on NW, followed by red dust on NW. Dark dust on E side.
4.12.30 pm. Steam spurt NE.
4.14 pm. Roar, spurt of dust on E.
4.15 pm. Roar continues with spurting of dust and steam.

4.17 pm. Avalanche on NW.

4.18 pm. Strong quake—avalanche NW. Roar and spurting dust on east and continues very heavy. Red cloud on NW. Earthquake that dismantled both components.

4.23 pm. Dust cloud growing soft.

4.26 pm. Avalanche on NW and rise of dust cloud over entire pit.

4.31 pm. Spurt of steam and dust on E side.

4.32 pm. Dark dust cloud on E. Avalanche on NW.

4.33 pm. Soft cloud over entire pit.

F. Durning

May 21, Observer Finch, Observatory

4.55 to 5.05 pm. Small explosion.

5.08 pm. Heavy cloud especially from N.

5.14 pm. Dense dust cloud E side of pit.

5.18 pm. From N side also. Gas rush without explosive violence.

5.20 pm. Dense dust cloud SE side of pit.

5.40 pm. Pit being obscured by mist.

5.42 pm. Clear again.

5.53 pm. Avalanche NE.

6.00 pm. Small cloud from pit.

7.00 pm. Pit obscured for a time by mist.

7.18 pm. Mist has lifted, slowly rising steam cloud.

7.27 pm. Avalanche.

R. H. Finch

May 21–22, Observer Kirkpatrick, Observatory

7.30 pm. Heavy steam cloud. Avalanche.

7.32 pm. Heavy dust cloud rising on E.

7.35 pm. Slow rising cloud over entire pit.

7.44 pm. Soft dust cloud.

7.50 pm. Luminous flash in center of steam cloud.

7.53 pm. Luminous flash at left of pit cloud.

7.57 pm. Hazy momentary luminosity quite low over pit.

8.10 pm. Low cloud over pit rising, now has cleared.

8.30 pm. Too much fog and mist to see anything.

9.01 pm. Explosion.

9.05 pm. Flash high over pit.

9.27 pm. Pit cloud visible again. Not heavy.

9.35 pm. Fog has obscured the pit.

9.45 pm. Perceptible roar (wind?)

9.55 pm. Seeing improved. Little or no cloud volume.

10.13 pm. Moonlight shows presence of steam cloud over whole pit.

10.39 pm. Extensive, slowly changing steam cloud.

11.00 pm. Extensive, slowly changing steam cloud. No glow seen yet tonight.

11.20 pm. Pit covered by stationary steam cloud.

11.25 pm. Black cloud rising at right.

11.55 pm. Quiescent steam cloud over entire pit.

May 22

12.12 am. Quake; windows rattle, floor shakes.

12.14 am. Quake; windows rattle, floor shakes.

12.17 am. Quake; windows rattle, floor shakes.

12.25 am. Quake; windows rattle, floor shakes.

12.28 am. Steam cloud develops rapidly on NE side.

12.55 am. Perceptible quake.

P. H. Kirkpatrick

May 22, Observer Durning, Observatory

1.21 am. Feeble quake followed by steam and dust cloud over entire pit.

1.15 am. Heavy spurt dust on E side.

1.15.30 am. Slight quake. Steam cloud over entire pit.

1.17 am. Medium quake. E-W component dismantled.

1.21 am. Heavy steam cloud.

1.35 am. Quake dismantled E-W component.

1.37 am. Quake dismantled E-W component.

1.40 am. Moderately heavy cloud over pit.

1.44 am. Slight roar and spurt of dust NW.

1.47 am. Feeble quake, strong west tilt.

1.50 am. Spurting dust clouds E and N.

1.52 am. Feeble quake, dust cloud over entire pit.

1.55 am. Roar. Heavy dust cloud over whole pit.

1.58.30 am. Feeble quake.

2.09 am. Adjust seismograph to counteract west tilt.

2.10 am. Slight quake.

2.10.30 am. Strong quake, dismantled E–W component. Heavy dust cloud over whole pit. Explosion.

2.15 am. Heavy dust cloud over whole pit.

2.20 am. Prolonged quake starting at 2.10.30 has overcome west tilt. Heavy dust and steam drifting.

2.25 am. Small explosion or heavy gas rush with quake, dismantling both components.

2.30 am. Rush of gas continues.

2.30.30 am. Heavy roar, short duration.

2.33 am. Roar continues, rapid rise of heavy dust cloud.

2.34.30 am. Loud roar.

2.35 am. Roar continues very loud.

2.38 am. Heavy roar, dust cloud rapidly rising.

2.42 am. Roar continues.

2.45 am. Dust cloud still very heavy.

2.48 am. Heavy roar continues.

2.49 am. Roar continues heavy. Indications are that warning is received 20–25 minutes before a possible explosion.

2.59 am. Heavy roar.

3.01 am. Continued roar and heavy dust cloud.

3.05 am. Strong N–E tilt. Constant tremor.

3.10 am. Less dust. Steam cloud heavy.

3.30 am. Fog in crater entirely about pit.

3.35 am. Heavy roar.

3.47 am. Constant tremor goes on.

4.00 am. Mist has lifted. Steam and dust slowly rising over pit.

4.25 am. Steam cloud heavy. Slight roar.

4.26 am. Roar growing heavy, dust cloud on NW side.

4.30 am. Slowly rising steam. No dust.

4.45 am. Roar has been constant, but not heavy.

5.00 am. Fog obscures pit.

5.15 am. Steam cloud over whole pit, roar continues.

5.20 am. Roar continues. Steam cloud heavy.

5.30 am. Steam cloud very heavy, very little dust, roar continues.

5.37 am. Very heavy roar.

5.38 am. Red dust cloud on north.

5.40 am. Very heavy roar. Mr. Finch reports old vertical crack in Uwekahuna Bluff.

F. Durning

May 22, Observer Kirkpatrick, Observatory

5.48 am. Loud roar followed by dust on right.
5.53 am. Large avalanche cloud at right.
6.05 am. Very heavy dust clouds rising.

P. H. Kirkpatrick

May 22, Observer Finch, Observatory

Inspection of Uwekahuna Bluff revealed no crack in the new ash anywhere. The avalanching from the Bluff revealed old vertical zones of weakness. There is considerable debris at the bottom, especially at the S end of the "Daly Laccolith".

6.20 am. Red avalanche cloud from the N. There has been considerable avalanching during the night, though the pit rim is not very different from last night.

6.43 am. Avalanche NW.
6.53 am. Continuous roar.
7.24 am. Avalanche cloud W.
7.44 am. Dense reddish cloud N.
8.00 am. Heavy steam cloud.
8.05 am. Heavy steam cloud.
8.07 am. Quake. Both instruments dismantled.
8.09 am. Tremors continue.
8.09.30 am. Dense cloud.
8.10 am. Explosion. Rocks all north.
8.10.30 am. Explosion center of pit.
8.11 am. Still exploding. Lightning.
8.18 am. Thunder. Rapid rise of cloud apparently from NNE portion of pit.

8.30 am. O. H. Emerson, accompanied by Clark, Palmer, Stearns, Stokes, left for airplane landing field, and trip through W gap Kilauea, across desert and out at Half-Way House.

R. H. Finch

May 22, Observer Durning, Observatory

8.25 am. Dust cloud softer at base and drifting SSW.
8.30 am. Steam cloud still heavy with gray dust.
8.34 am. Heavy avalanche on NNW.
8.37 am. Heavy red dust cloud over entire pit.
8.39 am. Roar, dense cloud, steam and dust.
8.40 am. Dust cloud continues to rise fast and strong.
8.42 am. Constant harmonic tremor, roar at pit, heavy avalanche cloud on NNW.
8.45 am. Very heavy dust cloud continues to rise on NNW.
8.46 am. Roar in pit.
8.49 am. Heavy black cloud on NW.
8.49.30 am. Dust falling at Observatory.
8.51.30 am. Heavy avalanche cloud.

F. Durning

May 22, Observer Finch, Observatory

8.55 am. Red dust SE following felt quake. Very dense.
8.57 am. Dense gray dust with quite rapid ascensional rate.
9.00 am. Red cloud.
9.02 am. Dense dust volutes N side of pit and small one near S rim.
9.18 am. Cloud voluminous but softer.

9.19 am. Avalanche NW, followed by reddish cloud with more rapid ascensional rate over entire pit.

9.24 am. Roar from pit.
9.30 am. Avalanche from N.
9.33 am. Dense dust volutes NNE.
9.40 am. Red cloud from N.
9.59 am. Denser cloud N and NE.

10.03 am. More rapid steam cloud NE.
10.09 am. Red cloud from N following quake.
10.10 am. Very heavy steam and dust cloud from N. Cloud rising rapidly.
10.17 am. Rapid rise dust and steam cloud.

R. H. Finch

May 22, Observer Hinkley, Observatory

10.18 am. Rapid rise dust and steam cloud.
10.21 am. Avalanche NW side.
10.31 am. Very positive quake, instruments dismantled.
10.36 am. Small avalanche NE side, gas rising rapidly.
10.38 am. Avalanche NW side.
10.40 am. Avalanche NW side.
10.43 am. Avalanche NE side.
10.44 am. Avalanche NW side.
10.46 am. Heavy avalanche NE side; also NW. Gas rose strongly at NW avalanche.
10.47 am. Avalanche north side, cloud rose rapidly.
10.50 am. Slight avalanche E side.
10.55 am. Avalanche NW side.
10.57 am. Steam cloud NE side.
10.58 am. Steam cloud E side.
11.00 am. Avalanche NE.
11.02 am. Steam cloud E side.
11.05 am. Avalanche NE side.
11.06 am. Avalanche NE side
11.11 am. Large steam cloud NE side.
11.13 am. Avalanche NW side.
11.16 am. Two avalanches NW side.
11.36 am. Roar from pit, dust appeared in 1 minute.
11.41 am. Avalanche N side.
11.46 am. Avalanche and steam NE side.
11.50 am. Avalanche NW side.
11.51 am. Avalanche E side.
11.52 am. Avalanche and heavy dust cloud on eastern edge.
11.57 am. Rapidly rising cloud on NW and NE sides, followed by thick cloud along E–N–NW portions of pit.
12.00 noon. Avalanche NW side.
12.03 pm. Heavy cloud from whole pit.
12.26 pm. Much steam still visible at higher levels, dust clouds thinned out considerably and rising very slowly.
12.30 pm. Cloud apparently has very little dust in suspension. Fine and slow moving with its tip pure steam.
12.32 pm. Skyline apparent on NW for finger's breadth.
12.35 pm. Cloud still thin and pale. Movement slow.
12.50 pm. Dust and steam noticeably thinner with much smaller convection currents above pit.
1.20 pm. Both instruments dismantled by earthquake.
1.23 pm. Roar, of very short duration, at pit.
1.24 pm. Dense clouds appear.
1.25 pm. Dense cloud N edge.
1.26 pm. Clouds thinner and convection less.
1.32 pm. Cloud thickening on NW and along N face of pit. Gaseous activity increasing.
1.35 pm. Heavy and rapid dust cloud along north face. Continued 2 minutes. Cloud rose 3000 feet.
1.42 pm. Avalanche N side.

1.47 pm. Cloud thinner but rising rapidly.

1.51 pm. Heavy avalanche cloud east side mounting very rapidly.

V. Hinkley

May 22, Observer Finch, Observatory

1.58 pm. Small explosion at S side of pit. Lightning and thunder. Explosion confined to S side of pit. Lightning at rim of pit.

1.59 pm. Soft cloud N part of pit. Hard cloud S part of pit. Heavy roar continuous.

2.00 pm. Roar continuous. More lightning at rim. Cloud increases at central part of pit.

2.01 pm. Explosion continues.

2.02 pm. Roar continues. Explosion shoots to N from center of pit.

2.02½ pm. Another explosion. Cloud 8640 feet above Halemaumau, estimate by Stearns.

2.03 pm. Roar dies down.

2.03½ pm. Another explosion. Softer cloud rolls over NE rim. Heavy cloud spreads to N part of pit.

2.04 pm. Roar ceases. Cloud continues rising. Heavy fall of ash on Kau desert and S side Kilauea crater.

2.05 pm. Ascension rate of cloud diminishes.

2.07 pm. Ascension rate of cloud increases, in central part of pit.

2.09 pm. Cloud soft in N part. Still hard in S part.

2.10 pm. Another explosion east side of center of pit. N half of pit free from explosion cloud. Heavy roar. Lightning in upper cloud. Rocks falling SE side. Roar increases.

2.12 pm. Shower rocks. Lightning left side cloud. Explosion nearly continuous.

2.13 pm. Roar increases. Cloud soft in N side.

2.14 pm. Roar diminishes. Cloud softens over entire pit.

2.15 pm. Heavier cloud in central pit. Spreads to entire pit.

2.30 pm. Cloud diminishing.

2.35 pm. Roar at pit.

2.40 pm. Rapid rising of dense cloud at NE center of pit continous.

2.44 pm. Avalanche cloud NW.

2.50 pm. Avalanche on NW and spurt of dark dust cloud.

R. H. Finch

May 22, Observer Durning, Observatory

2.54 pm. Very heavy dark spurting dust cloud.

2.54.30 pm. Slight quake, roar at pit, rapid rise of explosive dust cloud strongest on N.

2.58 pm. Fast rise of steam heavy with red dust.

3.00 pm. Heavy dark dust and steam cloud on NNE.

3.02 pm. Avalanche on N.

3.02.30 pm. Spurt of steam and dust on E side.

3.07 pm. Avalanche continues on NW.

3.10 pm. Continued avalanche on NW, heavy steam cloud on E side.

3.14 pm. Moderately heavy quake. E–W component dismantled.

3.15.30 pm. Heavy spurt steam over whole pit.

3.19 pm. Constant spurting of steam over entire pit.

3.24 pm. Roar from pit.

3.24.30 pm. Avalanche on NW, heavy spurt of steam on E side.

3.25.30 pm. Spurting steam very heavy with dust. E–W component dismantled by moderate quake.

3.26.30 pm. Steam cloud softer. Changing to red avalanche cloud on NE.

3.30 pm. Continuous spurting of steam. Roar. Cloud growing heavier with dust.

3.31 pm. Avalanche on NW side.

3.31.30 pm. Slight quake.

3.34 pm. Heavy steam cloud over whole pit.

3.36 pm. Heavy roar with fast rising steam cloud on NW.

3.37 pm. Heavy rush of gas, some red dust in center of cloud and on NW side.
3.39 pm. Cloud growing softer.
3.40 pm. Roar and spurting dust cloud.
3.41 pm. Roar. Continued rise of dust.
3.41.30 pm. Roar. Heavy steam and not much dust.
3.42 pm. Spurt of very heavy red dust cloud.
3.43.30 pm. Cloud much softer.
3.50 pm. Steam cloud continues to rise but more slowly.
3.56 pm. Slight quake followed by spurt of steam on E side.
4.00 pm. Avalanche on NW side.
4.03 pm. Slowly rising steam cloud.
4.04 pm. Heavy avalanche NNW.
4.08 pm. Heavy steam on NW.
4.14 pm. Small avalanche on NW.
4.15 pm. Slight quake, spurt of steam and red dust cloud.
4.18 pm. Continued steam spurts—some red dust.
4.19 pm. Slight quake.
4.20 pm. Avalanche on NW. Steam spurt on E side.
4.23 pm. Continuous avalanche, very heavy on NW.
4.25 pm. Heavy steam cloud on E.
4.29 pm. Continuous steam, some dust.
4.34 pm. Spurt of steam on E.
4.36 pm. Small avalanche NW.
4.39 pm. Slight quake. N–S component out.
4.43 pm. Heavy spurt of steam SE side.
4.45 pm. Heavy steam on NE.
4.49 pm. Heavy spurts of steam continued.
5.01 pm. Avalanche on NW side.
5.03 pm. Heavy steam cloud over entire pit.
5.10 pm. Slight quake.
5.12 pm. Heavy steam.
5.16 pm. Heavy steam cloud on N.

F. Durning

May 22, Observer Finch, Observatory
5.20 pm. Cloud thin mostly from NE center of pit.
5.30 pm. Cloud a little heavier.
5.45 pm. Roar.
5.47 pm. Steam condensing from most of pit with rapid column NE.
6.07 pm. Denser cloud.
6.09 pm. Avalanche N side.
6.11 pm. Roar.
6.13 pm. Heavy red cloud NW.
6.15 pm. Roar.
6.16 pm. Heavy red clouds all over pit.
6.21 pm. Rapid cloud NE.

R. H. Finch

May 22, Observer Hinkley, Observatory
6.26 pm. Steam cloud NE side.
6.33 pm. Marked earthquake, E–W instrument dismantled.
6.36 pm. Dull roar followed by steam cloud NE side and by dense avalanche cloud.
6.38 pm. Steam cloud NE side.
6.49 pm. Clouds rising slowly, some steam on NE side.
6.55 pm. Cloud mounting higher and more rapidly.

V. Hinkley

May 22, Observer Durning, Observatory

7.00 pm. Durning found E–W component seismograph out—replaced same 7.02 pm.
7.05 pm. Spurting steam cloud on E side.
7.11 pm. Medium heavy earthquake, dislodged E–W component.
7.19 pm. Constant harmonic tremor.
7.21 pm. Pit obscured by fog.
7.23 pm. Roar at pit.

F. L. Durning

May 22, Observer Finch, Observatory

7.30 pm. Avalanche on SW. Slight roar.
7.31 pm. Mist drifting in obscuring pit.
7.32 pm. Mist clearing. Steam cloud slowly rising. No dust.
7.34 pm. Dust cloud on E side.
7.35 pm. Slight roar at pit.
7.36 pm. Dust cloud on NW. Fog closing in. Pit obscured.
7.46 pm. Fog clearing.
7.48 pm. Fog closing in.
7.50 pm. Steam cloud over pit—very light.
7.51 pm. Short light quake, clearing over pit.
7.54 pm. Heavy dust cloud.
7.56 pm. Slight rumbling at pit.
7.58 pm. Fog shut down on pit.

R. H. Finch

May 22, Observer Durning, Observatory

8.06 pm. Fog heavy over pit.
8.10 pm. Continuous harmonic tremor.
8.15 pm. Constant tremor and feeble quakes strong on N–S component.
8.23 pm. Slight roar. Mist still very heavy over pit.
8.26 pm. Feeble quake, stronger on NS component.
8.27 pm. Slight roar. Pit obscured by fog.
8.38 pm. Slight tremor strong on NS component.
8.50 pm. Slight quake, stronger on NS component.
9.00 pm. Very slight earthquake.
9.09 pm. Slight quake.
9.27 pm. Both components dismantled.
9.40 pm. Quake continued for 1 minute.
9.42 pm. Harmonic tremor strong SE tilt.
9.43 pm. Tremor merged into quake.
10.04 pm. Feeble quake merged into tremor.
10.15 pm. Slight quake merged into tremor.
10.40 pm. Rain and mist obscured pit. Number of feeble earthquakes and constant tremor.
10.44 pm. Slight quake.
10.52 pm. Moderate quake.
10.52.30 pm. Moderately strong quake. Both components dismantled.
11.07 pm. Slight quake.
11.10 pm. Constant tremor.
11.15 pm. Slight quake. Pit obscured by mist.
11.18 pm. Moderate heavy quake, dismantled E–W component.
11.25 pm. Slight quake.
11.26 pm. Earthquake, both components dismantled.
11.27 pm. Earthquake, E–W component dismantled.
11.45 pm. Clearing over center, heavy steam cloud.
11.46 pm. Heavy shock, both components out.

F. Durning

Bowlder Impact Southeast of Halemaumau, note by Kirkpatrick

Memorandum relative to trip to aviation field this morning. Those present: Emerson, Gregory, Clark, Palmer, Stearns, Stokes, Tai Sing Loo, Kirkpatrick.

About 150 yards from "eight ton bowlder" and in general direction of the pit, a smaller bowlder of similar material was observed. The volume of the bowlder is estimated as between one and two cubic feet. It was in two parts as if broken by landing. The larger piece, comprising probably three-fourths of the whole, was at the brink of the basin produced by impact.

The smaller piece was a yard away and on a line with the basin and the larger piece. The basin had a depth of about eight inches and it's surfaces were composed of scattered gravel except that surface on the side opposite the bowlder.

This surface for an area of about a third of a square foot was of moist, cohesive black dirt and exhibited with beautiful distinctness the scoring occasioned by the incident bowlder. The inclination of the scored surface to the horizontal was between forty and fifty degrees. The scorings were in the form of parallel lines; probably two dozen separate lines would have been distinguishable. The scored surface was nearly plane.

The plane of incidence as indicated by the scorings was observed to align correctly with the positions of the bowlder fragments so that the horizontal direction of motion of the bowlder at incidence can scarcely be in doubt.

It was further observed that this direction produced did not intersect the pit at any point. A straight line drawn from the bowlder to the pit could not make with the plane of incidence of the bowlder an angle smaller than about thirty degrees.

It was the opinion of most of those present that the bowlder had fallen this morning. The freshly cloven earth showed no evidence of having been rained upon. No mud spatter could be observed on or about the bowlder. The temperature of the bowlder both at its surface and at freshly broken faces was in my opinion not above that of the surroundings however. Temperature was tested by contact with the hand and with the lips.

The district for several hundred feet was examined for other recent stones but none was observed.

The discrepancy between the direction of the pit and the plane of incidence of the bowlder would seem too great to explain by windage or rotation. The windage assumption would require a wind force on the bowlder equal to about one third of its weight. The parallelism of the scorings precludes a pronounced rotation (except about a horizontal axis). It might be supposed that the bowlder had been deflected by striking the earth at an earlier point. No such landing spot was observed and it may be safely stated that there was none within 25 yards of the observed position.

Paul Kirkpatrick

Bowlder Impact, note by T. A. Jaggar

The position of the impact pit described by Professor Kirkpatrick is approximately 1500 feet southeast from the Halemaumau rim, or 3000 feet from the Halemaumau center. A block of 1.5 cubic feet would be quite capable, in an explosive blast from the pit, of going up from 500 to 1000 feet in the midst of excessively hot vortical whirls. Such a blast at 2.15 am. was described for this date, May 22, in the Observatory notes of the night-time by Mr. Durning. The spurts of dust from the pit at 1.44 am. and at 4.26 am. were described as rising at the NW side of Halemaumau; these would fling stones out in a barrage to the southeast and the trade wind was presumably blowing from northeast. The combination of convectional uprush of hot vapor and deflection by wind regularly produces tornadoes on the edge of Halemaumau when there is anything hot inside the pit. These tornadoes traverse the direction of the wind at oblique angles in their movement of translation, and carry large stones with ease. Where a steam-blast eruption was in progress, bowlders could be carried, and the direction of their final fling, in striking the ground, would be a tangential direction to the upright whirl of the vortex as the tornado migrates. This might easily vary thirty degrees from the general trajectory of the barrage. (Plates 51, 52).

I have seen tornado convection of this character over hot fountains of lava in March 1921, carrying forty-pound blocks of crust hundreds of feet into the air, and dropping them 300 feet away from the lava lake. Every cauliflower cloud eruption is full of tight vortical whirls and it is precisely this vortex action which drives bombs with such violence as was demonstrated at St. Pierre in Martinique, so that 12-inch bowlders punctured steel boiler plates of the rum factories. The movement of translation of the cloud was relatively slow, but the internal velocities of the vortical bundles, carrying ash, were high.

May 23, Observer Finch, Observatory

12.05 am. Quake. EW dismantled.
12.18 am. Quake. EW dismantled again.
12.43 am. Slight roar.
12.53 am. Slight roar like avalanche.
1.10 am. Pit obscured by cloud.
1.13 am. Light observed on Uwekahuna Bluff. Flashlight carried by some person.
1.15 am. Quake-instrument dismantled.
1.25 am. Roar.
1.27 am. Loud roar of some duration.
1.30 am. Mist lifted and the ordinary heavy steam cloud observed.
1.55 am. Pit obscured by mist.
1.59 am. Quake.
2.20 am. Quake.
2.22 am. Quake. Instrument dismantled.
3.05 am. An explosion.
3.10 am. Quake. Instrument dismantled. Rocking continued for 3 or 4 sec. Roar at pit.
3.30 am. Roar from gas rush or small explosion.
4.00 am. Heavy steam cloud.
4.20 am. Pit obscured.
4.52 am. Quake. EW dismantled.
4.59 am. Quake. EW dismantled.
5.15 am. Very thick steam cloud with but little dust.
5.37 am. Quake, instrument dismantled.
5.40 am. Rapid rise of steam from the usual vent NE side pit.
6.16 am. Avalanche with red dust NW.
6.40 am. Cloud nearly all steam. (Photo)

R. H. Finch

May 23, Observer Hinkley, Observatory

7.07 am. Dense steam cloud NE. Slight avalanche NW.
7.10 am. Pure steam very dense along N face.

V. Hinkley

May 23, Observer Finch, Observatory

7.27 am. Heavy red and dense cloud NW.

7.29 am. Quake. EW dismantled followed by avalanche NW and apparent increase steam from NE vent.

7.53 am. Quake followed by dense cloud rather red all over pit. A small explosion.

R. H. Finch

May 23, Observer Palmer, Observatory

7.54 am. Steam replaced by dust cloud over whole area of pit. Reddish brown. Two centers. Rising to great height and rapidly.

7.57 am. A new puff of smoke starting at north side of crater. #

Meaning Halemaumau pit.

8.00 am. A new puff starts, rising fairly rapidly. Rising on right side of crater.

H. S. Palmer

May 23, Observer Finch, Observatory

8.04 am. New puff hard outlines.
8.08 am. Quake.

R. H. Finch

May 23, Observer Emerson, Observatory
8.52 am. Small puff of dust on SE.
9.00 am. Explosion cloud NE. No roar heard or fall of rocks at first.

O. H. Emerson

May 23, Observer Finch, Observatory
9.05 am. Roaring and fall of rocks developed. A very large cloud arose, with lightning. Definitely an explosion.
9.14 am. Heavy fall ash on desert.
9.15 am. Rapid rise dust cloud SE.
9.50 am. Rapid rise dust cloud NE side of pit.
10.00 am. O. H. Emerson and V. Hinkley left to explore N half of crater.
10.12 am. Steam rising rapidly N side.
10.25 am. Small avalanche S side.
10.40 am. Steam and dust cloud very thin at times.

R. H. Finch

May 23, Observer Durning, Observatory
11.30 am. Moderately heavy steam cloud, very little dust.
11.35 am. Steady steam cloud on N side, very light haze over the rest of pit.
11.37 am. Avalanche on NW.
11.45 am. Steam still very heavy, very little dust.
11.53 am. Moderately heavy quake. NS comp. dismantled.
11.54 am. Heavy red dust cloud on NW.
11.54.30. Heavy spurt steam on W. Continued rise red dust on NW.
11.56 am. Red dust spurts over whole pit. Steam continues heavy.

F. Durning

May 23, Observer Finch, Observatory
12.07 pm. N-S dismantled. No. 1 position of seismogram line previous to last quake: No 2 present line.

R. H. Finch

May 23, Observer Durning, Observatory
12.14 pm. Moderately heavy steam cloud.
12.20 pm. Continuous rise of steam, very little red dust.
12.22 pm. Avalanche on NW, very heavy spurt of steam on N side of pit.
12.23.30 Avalanche on N side.
12.25 pm. Steam cloud continues.

F. Durning

May 23, Observers Finch and Burdick, Observatory
12.46 pm. Cloud thinning, rim of crater visible.
12.56 pm. Large steam cloud.
1.00 pm. Slight avalanche on west side.
1.10 pm. Large steam cloud.
2.09 pm. Pit very clear, rim visible.
2.12.30 pm. Steam cloud.*
2.36 pm. Heavy steam cloud.
3.02 pm. Heavy steam cloud.
3.06 pm. Dust cloud.
3.07 pm. Lightning.
3.08 pm. Explosion NE center.
3.08.30 pm. Cloud rising rapidly NE pit.
3.09 pm. Small explosion NE center. Another explosion.
3.09.30 pm. Explosion. Lightning.
3.10 pm. Explosion. Rocks falling into pit.
3.10.30 pm. Explosion center.

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*See timepiece note 2.40 am. May 24.

3.11 pm. Explosion.
3.11.30 pm. Lightning. Explosion. Rocks outside with dust behind NNE.
3.12 pm. Explosion, lightning. Lightning between 2 cloud volutes.
3.12.30 pm. Lightning low in pit. No clouds NE explosion vent.
3.13 pm. Hard clouds continue to rise NE of pit.
3.13.30 pm. Void over NE explosion pit still continues.
3.15 pm. Heavy dust clouds continue.
3.15.30 pm. Clouds lighter, still rising.
3.16.30 pm. Fresh outburst dust cloud.
3.19 pm. Large cloud still rising—mostly steam.
3.21.30 pm. Explosion or gas rush.
3.23 pm. Heavy dust clouds.
3.25 pm. Heavy dust clouds continue.
3.27 pm. Heavy dust cloud continues.
3.30 pm. Heavy cloud.
3.37 pm. Heavy steam cloud.

R. H. Finch dictating
With Allen Burdick recording

May 23, Observer Finch, Observatory

4.15 pm. Heavy steam cloud NE center of pit.

4.33 pm. Rapid steam ascent NNE. On two different occasions there have been what appeared to be explosions within the cloud 2,000 feet above the pit. The cloud shot out horizontally with all the appearance of an explosive cloud. This cloud and also one other were noted by Capt. Perkins.

6.08 pm. Heavy steam cloud.
6.10 pm. Heavy gas rush with dark gray cloud S half of pit.

R. H. Finch

May 23, Observer Hinkley, Observatory

6.21 pm. Gaseous activity on the increase.
6.30 pm. Steam arising NE.
6.32.30 pm. Steam rush N side.
6.36 pm. Gas arising E.
6.39 pm. N and E gas clouds.
6.42 pm. More steam escaping E.
6.45 pm. Rush of steam E.
6.50 pm. Steam cloud rising higher and more heavily.
6.55 pm. Plume of steam from NE side.
6.58 pm. Rush steam apparently from W side.
7.10 pm. Too dark to see pit at all distinctly. Plume of steam continues.

V. Hinkley

May 23, Observer Durning, Observatory

7.15 pm. Slow rise of steam over entire pit.
7.25 pm. Steam cloud very light.
7.40 pm. Only a very light cloud over pit.

F. Durning

May 23, Observer Palmer, Observatory

8.00 pm. Cloud over pit is low.
8.23 pm. Cloud continues small and low.
8.34 pm. Cloud grown slightly.
8.46 pm. Some further growth of cloud.
8.54 pm. About as observed last.
8.57 pm. Cloud is not clearly visible, but seems to be chiefly steam.
9.07 pm. Cloud decreased a little.
9.28 pm. Cloud merged with overhead cloud.

9.31 pm. Cloud low and thin.
9.41 pm. Low, narrow thin cloud.
9.43 pm. Very slight steam cloud.
9.48 pm. Cloud growing again.
10.10 pm. Slight earthquake. Cloud still small.
10.15 pm. Cloud still small.
10.25 pm. Cloud small.
10.28 pm. Cloud rather taller but still narrow.
10.50 pm. Moderate sized cloud, but so thin that I can see the whole rim of the greater crater.
11.03 pm. Thin, but fair sized cloud at times.
11.21 pm. No change in cloud.
11.33 pm. No change in cloud.
11.44 pm. Cloud has thickened somewhat but is still rather small.
12.00 m. Cloud of fair size and density.

H. S. Palmer

May 24, Observer Finch, Observatory
12.10 am. Cloud thick probably as voluminous as during the day May 23.
1.15 am. Pit became obscured by mist.
1.33 am. Pit obscured. Quake. (report of felt quake Hilo and Waiakea at 1.22 am.)
1.40 am. Pit obscured. Quake.
1.42 am. Part of pit in view, large cloud of steam showing.
1.48 am. Large steam cloud continues. *Kapoho District Report* (L. A. Thurston made an inspection of the Kapoho district on May 23 and reported through McSwanson that there has been no further movement in that region.)
2.01 am. Quake.
2.28 am. Quake.
2.30 am. Pit obscured.
2.40 am. Usual heavy steam cloud.

Watch Correction. The watch that timed the explosion during the 3 pm., 23, eruption was found to be 50 sec. slower than Observatory clock at 3 am. Watch had been losing about 50 sec. a day, was set correct in morning May 23.

2.54 am. Nearly continous tremor on seismograph.
3.05 am. Steam cloud heavier.
3.22 am. Loud crack noise, fraction of a second at pit, more like the thunder of a short lightning flash than avalanche. No lightning observed. Teddy, the dog, showed surprise and came into house. Could this be a small explosion of gas above the rocks in bottom of pit? (The three supposed explosions of gas in the pit heard from Algae locality morning of May 17 may have sounded similar to the 3.22 one if at same distance.)
3.26 am. Quake.
3.48 am. Quake. This quake, as in the cases of many others, caused the E or SE part of the building to creak first, followed by windows rattling on W side of building.
5.10 am. Quake preceded by rumble.
5.51 am. Quake, both components dismantled.
5.57 am. Heavy clouds with moderately hard outlines.
6.00 am. Usual heavy steam cloud.
6.43 am. Quake.
7.05 am. Avalanche E.
7.07 am. Small avalanche followed by spurt of steam on N.

R. H. Finch

May 24, Observer Durning, Observatory
7.10 am. Photo steam cloud. #6 film pack.
7.15 am. Avalanche on E side, steam still very heavy.
7.20 am. Avalanche dust clouds on N and E.

7.30 am. Slight quake. NS component dismantled. Small avalanche from cliff in front of Observatory.

7.31 am. Heavy avalanche clouds NW. Small avalanche on E.

7.35 am. Avalanche dust clouds rise with steam.

7.40 am. Enough dust to darken entire steam cloud.

7.42 am. Dust cloud continues on NW.

7.45 am. Much less steam, red dust on NE.

F. Durning

May 24, Finch and Hinkley, Observatory

Note on Erosion during Downpour. On the afternoon of May 18, the torrential downpour eroded the old and somewhat consolidated ash deposit in some places to a depth of 2 inches, despite the fact that the heavy rain lasted less than an hour. The tremendous convection cloud developed by explosions can easily develop downpours as vigorous as in any thunderstorm, not by condensation of volcanic steam, but by insuck of atmospheric moisture. (Finch, 1930.)

R. H. Finch

7.50 am. Steam rising in spurts, very light dust.

7.55 am. Small avalanche on NW.

8.05 am. Small avalanche on NW.

8.09 am. Heavy explosion steam and dust cloud on E side.

8.10 am. Cloud on E much lighter.

8.26 am. Dense cloud arose from all over pit, probably gas rush of moderate energy.

8.30 am. Another explosion or gas rush.

8.32 am. Puffs of rapidly rising clouds.

8.43 am. Quake.

9.10 am. Heavy dust clouds rose rapidly in puffs.

9.13 am. Explosion NE center pit-lightning, more explosion.

9.14 am. Other explosions heavy—most vigorous explosion for several days.

9.14.30 am. Lightning, many rocks, smoke from volutes at 9.15 am, rocks fully 3,000 feet high.

9.15.30 am. Explosion continues. Lightning in middle of cloud. Short cracks of thunder, rocks falling to north.

9.17.30 am. Another explosion center pit, quite violent, blocks of rocks to north. Dense black clouds in explosion.

9.18.30 am. Another violent explosion. Dust cloud above 6,000 feet. Rapid rise of dust continues.

9.24 am. Dust cloud continues to rise rapidly.

9.25.30 am. Tremor felt. Lightning in cloud. Rapid rise dust on NW.

9.26.30 am. Horizontal cloud shot out NW side about 700 feet above lip of crater. Heavy deposit ash added N and S sides.

9.35 am. Eruption completely over. Dust clouds still boiling out of pit but much thinner.

9.37 am. Activity increases along north face with clouds thicker and rising more rapidly. Heavy gas rush NE side.

9.39.30 am. Heavy clouds along E and N sides.

9.40.30 am. Whole pit filled with heavy cloud.

9.41 am. Powerful gas rush E. Cloud up 4,000 feet. Activity general over whole pit.

9.43.30 am. Activity shifted to NW with dense clouds rising.

9.54 am. Light avalanche clouds NW side.

R. H. Finch
V. Hinkley, recording

Watch about 1 min. fast.

10.15 am. Heavy dust cloud continues.

10.24 am. Rapid rise of dust.

10.45 am. Dust cloud continues.

R. H. Finch

May 24, Observer Wentworth, Observatory

10.51 am. Rapid rise dust continues.
10.53 am. Another puff (avalanche cloud?). Continued rise of fine dust.
10.55 am. Main stream and coarser on left side of column.
10.56 am. Increasing gradually.
10.57 am. Growing cloud.
11.00 am. Another increase of cloud after waning. Rather heavy cloud continues blowing strongly to SW.
11.06 am. Broad cloud continues. Blows away to SW before reaching great height.
11.08 am. Increased rise of dust.
11.13 am. Dust rise from left edge.
11.19 am. Cloud increasing.
11.21 am. Pinkish puffs to right side.
11.25 am. Cloud increasing on right.
11.29 am. White topped column, white portion rises above dust colored part.
11.33 am. White steam higher, dust below increasing.
11.40 am. Continued increase.

C. K. Wentworth

May 24, Observer Hinkley, Observatory

11.41 am. Avalanche NW side, light cloud.
11.45 am. Steam cloud over pit.
11.48 am. More steam.
11.49 am. Light dust cloud NW.
11.55 am. Steam jet E side. Noon: Cloud thin, mainly steam.
12.08 pm. Sharp quake. NS instrument dismantled. Dust cloud NW side.
12.09.30 pm. Another quake. Cloud rushing higher at NW. Steam escaping NE.
12.14 pm. Steam cloud high over pit.
12.20 pm. Avalanche cloud NW side. Cloud rather thin, mostly steam.
12.21 pm. Steam rush N side.
12.23 pm. Steam rush E side.
12.24 pm. Heavy dust cloud appears NE edge.
12.30 pm. Steam puff E side.
12.34 pm. Steam clouds from E side.
12.36 pm. Steam puff NW side followed by dust cloud, rather thin along N face.
12.38.30 pm. Steam rush N center.
12.41 pm. Large cloud of steam high over pit. Dust cloud quite thin.
12.50 pm. Steam puffs N center.
12.53 pm. Steam puffs E side.

V. Hinkley

May 24, Observer Finch, Observatory

12.57 pm. Avalanche dust NW following quake.
1.04 pm. Dense steam, dust cloud NNE.
1.08 pm. Heavy quake.
1.10 pm. Quake. N–S dismantled.
1.24 pm. Small avalanche NNE.

R. H. Finch

May 24, Observers Wentworth and Finch, Observatory

1.38 pm. Increasing steam on SE.
1.40 pm. Column nearly obscured by nearby mist.
1.45 pm. Clearing.
1.48 pm. Heavy steam clouds.
1.51 pm. Heavy steam cloud on SE.
1.55 pm. Heavy steam clouds on NE. Dust clouds on E and N.

1.58 pm. Steam clouds on E. Rolling up in strong billows.
2.02 pm. Steam clouds at NE, slight dust SE and NW.
2.08 pm. Moderate shake.
2.10 pm. Increased steam and dust clouds.
2.15 pm. Further increase in steam clouds with light dust.
2.18 pm. Very pronounced steam rising from N rim.
2.21 pm. Steam from NE.
2.23.30 pm. Stronger shake. Increasing steam.
2.30 pm. Rather strong steam and dust rising.
2.35 pm. Increased wind and dispersal of steam and dust.
2.41 pm. Steam clouds strong on NE. Slight dust on other margins.
2.46 pm. Increased steam cloud on east. Relatively little dust.
2.50 pm. Strong steam clouds.
3.01 pm. Strong steam from center, dust slight and blown away.
3.10 pm. Very little dust—steam jets swinging side to side.
3.30 pm. Slight quake.
3.32 pm. Another quake. Increased steam and moderate dust.
3.52 pm. Continued strong steam with little dust.
3.54 pm. Shake. Moderate. Heavier steam, commencing to mist between crater and here.
4.05 pm. Increasing steam at north rim. Little dust.
4.08 pm. Continued heavy steam.
4.15 pm. Continued heavy steam.
4.23 pm. Continued heavy steam.
4.30 pm. Steam cloud reduced. Shifting.
4.37 pm. Heavier steam.
4.43 pm. Strong avalanche dust cloud, first for some hours.
4.50 pm. Continued heavy steam.
5.00 pm. More steam.
5.03 pm. Increasing steam.
5.06 pm. Mist.
5.30 pm. Alternating mist and clear.
5.38 pm. Increasing steam cloud. No dust.
5.46 pm. Small avalanche cloud on NW. Strong steam cloud rest of pit.
5.49 pm. Very strong billowy steam from whole pit.
5.55–59 pm. Several slight quakes but no explosion.
6.08 pm. Increasing steam.
6.12 pm. Strong steam rising.
6.14 pm. Avalanche cloud at SE.
6.18 pm. Increasing steam.

C. K. Wentworth

7.00 pm. Heavy steam cloud continues.

R. H. Finch

8.38 pm. Steam cloud continues.
8.53 pm. Meteor.
8.57 pm. Swaying type of earthquake lasted 3 to 4 seconds.
9.08 pm. Several quakes. Heavy clouds.
9.18 pm. Steam clouds continue.
9.54 pm. Meteor.
10.35 pm. Quake. Seismograph N-S component dismantled.

C. K. Wentworth

May 25, Observers Emerson, Finch and Wentworth, Observatory

12.20 am. Slight roar. Night too dark to see anything and too windy to hear. Numerous slight quakes being recorded, but none felt for some time.

1.03 am. Feeble quake.

1.05 am. Moderate quake.

1.58 am. Moderate quake.

O. H. Emerson

2.10 am. Heavy steam cloud continues.

2.14 am. Quake.

2.18 am. Quake stronger. N–S dismantled.

2.30½ am. Quake. N–S dismantled.

2.35 am. Steam cloud appears heavier than usual.

3.00 am. Very small quake, SE corner of building affected first.

4.00 am. Steam cloud continues heavy.

4.40 am. Steam cloud thinner.

4.43 am. Quake.

4.45 am. Cloud thicker with steam rising in quite narrow column from NE vent.

4.50 am. S and SE parts of pit clear. Steam arising from N part only. SW wall Halemaumau visible.

5.13 am. Quake. N–S dismantled. Avalanche NW diffused dust all over pit.

5.19 am. Heavy dust volutes S side.

5.44 am. Avalanche N. Quakes stronger and more numerous during night May 24–25 than during night May 23–24. Photo 6.15 am. F.P. No 8.

R. H. Finch

7.05 am. Dust cloud.

7.13 am. Increasing steam and dust cloud.

7.16 am. Dust cloud on SE. Steam at NE.

C. K. Wentworth

7.20 am. Roar for about 1 sec at pit. Dust cloud NW 7.22.

7.28 am. Roar for 8–10 sec.

7.29 am. Dust cloud appeared with hard outlines, became diffused at 7.32.

7.41 am. Red dust N.

7.55 am. Roar over 10 sec.

7.56 am. Cloud appeared N.

7.58 am. Roar. Steam puffs NE. Sound continues.

R. H. Finch

8.10 am. Column of steam rising from central portion of pit, some dust elsewhere. Fume generally very thin.

8.15 am. Small avalanche cloud S.

8.53 am. Avalanche on NW.

9.03 am. Avalanche on S.

9.08 am. Steam increasing NE.

O. H. Emerson

May 25, Observer Durning, Observatory

9.15 am. Steam on N very light over whole pit.

9.21 am. Slight avalanche NW side.

9.28 am. Entire rim of pit visible. Fume very thin.

9.30 am. Heavy avalanche cloud N.

9.32 am. Heavy steam cloud.

9.35 am. Entire rim visible. Fume very thin.

9.39 am. Spurting steam cloud north. No dust.

9.43 am. Entire rim visible. Slight fume only.

9.44 am. Avalanche N side.

9.45 am. Slight roar in pit.

9.46 am. Slowly rising steam and dust cloud NE.

9.47 am. Heavy steam cloud NW, some dust.

9.50 am. Heavy steam cloud N side.

9.51 am. Slight earthquake.
9.52 am. Roar in pit. Red dust cloud N.
9.53 am. Spurting steam cloud N. NW dust cloud—heavy roar in pit.
9.54 am. Roar continues—heavy steam.
9.54.40 am. Dust cloud heavy and steam. Steam and dust cloud rising rapidly over entire pit.
9.56 am. Roar in pit slight.
9.57 am. Dust cloud slowly rising over entire pit.
10.00 am. Slight roar in pit.
10.01 am. Avalanche cloud NE.
10.02 am. Spurt steam cloud heavy with dust NE.
10.05 am. Spurt steam cloud N side. No dust.
10.07 am. Heavy roar in pit.
10.08 am. Heavy roar in pit.
10.12 am. Steam cloud. No dust.
10.14 am. Roar heavy. Continues heavy.
10.15 am. Heavy dust cloud rising NW.
10.16 am. Dust and steam cloud spreading over entire pit.
10.19 am. Spurt steam cloud center of pit.
10.20 am. Continued rapid cloud. 'Steam and dust.
10.28 am. Light haze over pit.
10.35 am. Slight avalanche E side.
10.44 am. Steam and dust cloud N side.
10.46 am. Pit clear. Very light steam.
10.49 am. Slight roar in pit.
10.55 am. Heavy spurting steam, dust cloud NW. Loud roar in pit.
10.56 am. Heavy dust cloud NW.
10.59 am. Slight avalanche N side, spurt steam and dust on N.
11.01 am. Heavy roar in pit.
11.03 am. Heavy steam and dust cloud NW.

F. Durning

May 25, Observers Finch, Hinkley and Emerson, Observatory

11.14 am. Landslide.
11.21 am. Roar for 28 sec. Explosion cloud appeared at NE in 1 minute. No rocks seen.
11.24 am. Cloud turns pinkish gray, as if from avalanche.
11.26 am. Rapid rise steam cloud, followed by red avalanche.
11.38 am. Heavy quake. N–S dismantled.
12.14 pm. Heavy steam denser than any time since daylight.
12.18 pm. Roar. Explosion in NE side of pit of short duration.
12.19 pm. Quake. N–S dismantled.
12.20 pm. Cloud getting thinner.

R. H. Finch

12.24.30 pm. Explosion, very definite roar. Mist obscured pit and made observation difficult. Dust cloud spread all over pit.

12.26 pm. Cloud still rising rapidly on NE and E sides of pit.

12.27.30 pm. Noises of explosion could be heard.

12.29 pm. Activity lessening. Hollow over explosion spot visible. Cloud still quite heavy.

12.31 pm. Lightning flash, short, and report of thunder. More thunder. Steady cannonade.

12.32 pm. Another explosion. Thunder, more thunder. Roar ceased. Lightning flash at left. Thunder aloft. Heavy cloud E and NE sides.

12.33 pm. Cloud still rising rapidly. Heavier thunder.

12.34 pm. Peals of thunder continue.

12.35 pm. Cloud still forced up strongly along whole face of pit.

12.35.30 pm. Peals of thunder.

12.36 pm. Very heavy thunder. Overhead flash of lightning.

12.37 pm. More lightning and thunder. Flash outside pit to right.

12.38 pm. Thunder from vertical flash over Military Camp.

12.39 pm. Clouds still rising rapidly. Thunder continues. Whole countryside towards Uwekahuna Bluff obscured by dust cloud and by mist; birds singing cheerfully about Observatory.

12.40.30 pm. Thunder continues. Mist obscures whole right half of pit. Cloud visible a little on left side.

12.43 pm. Mist lifting.

12.48 pm. Activity ceased.

12.55 pm. Mist cleared away. Pit visible entirely.

12.56 pm. Roar from pit. Light dust cloud NE side.

12.57 pm. Dust mounts NW side.

V. Hinkley

12.58 pm. Steam rising rapidly NE.

R. H. Finch

1.45 pm. Strong clouds rising. Mist obscured pit since 12.30.

1.46 pm. Explosion occurred.

3.13.30 pm. Quake.

5.55 pm. Crater obscured by near mist practically whole afternoon. Slight glimpses show clouds still rising, but no details were seen.

O. Emerson

6.30 pm. Pit obscured by mist and fog.

R. H. Finch

May 25, Observer Durning, Observatory

7.05 pm. Moderate quake. (Note—Gas engines of light plant running making it hard to hear any possible sound from pit)

7.15 pm. Fog still obscured pit.

7.36 pm. Fog lighter on E of crater. Pit still obscured.

8.45 pm. (E-W component on 9th revolution of drum is following exact path of 8th revolution due to west tilt)

9.00 pm. Still very hazy over crater.

9.30 pm. No change.

10.00 pm. Less change than before.

11.00 pm. Still heavy fog.

12.00 pm. Fog still heavy.

F. Durning

May 26, Observer Finch, Observatory

12.48 am. Roar at pit.

1.09 am. Roar at pit for 25 sec.

1.59 am. Roar at pit for 40 sec.

2.13 am. Roar at pit for 10 sec. Fog and mist continuous since 12.30 am.

2.14 am. Roar at pit 5 sec.

2.45 am. Roar at pit 5 sec.

2.59 am. Roar at pit 5 sec.

3.00.20 am. Loud roar at pit 4 sec.

3.06 am. Roar for 20 sec.

3.19 am. Loud roar lasting 1 min.

3.33 am. Roar.

3.34.30 am. Roar 10 sec.

3.36 am. Roar. Watch slow 1 min. 30 sec. for these times.

3.39 am. Very loud roar.

3.53 am. Roar 5 sec.

4.03 am. Roar became louder at 4.04. Died down somewhat and was very loud at 4.05.30.

4.33 am. Roar.

4.45 am. Convection current over pit drifting toward Military Camp, base of cloud 3,000 feet.

4.54 am. Slight roar. No dust cloud was afterwards noticed nor could any change be detected in the heavy steam column above pit.
5.23 am. Slight roar.
5.25 am. Heavy roar.
5.32 am. Roar becomes heavier and lasted 20 sec.
5.33 am. Another roar.

R. H. Finch

May 26, Observer Emerson, Observatory
5.52 am. Slight roar, 2 sec.
5.53 am. Louder roar, with thumping. Lasts 8 sec.
5.57 am. Moderate roar.
6.01 am. Slight roar. Morning misty. Pit barely visible.
6.36 am. Very slight roar.

O. H. Emerson

May 26, Observer Finch, Uwekahuna and Observatory

Uwekahuna Inspection. Inspection at Uwekahuna 6.15 am. showed a heavy deposit of rather fine pisolitic ash. A continuous roar could be heard from the pit and occasionally a sharp cracking noise like the sudden snapping of a rock. It appeared that there were new small cracks on the crater floor running from the Bluff toward the pit.

6.51 am. Roar.
6.56 am. Loud roar 16 sec.
7.30 am. Continous roar could be heard from Observatory. Roar louder 7.35 and 7.40.
7.41 am. Louder roar at 7.42.
7.45 am. Quake accompanied by loud roar that continued for 35 sec.
7.46 am. Loud roar.

R. H. Finch

May 26, Observers Emerson and Finch, Observatory
8.06 am. Moderate quake, dismantled both instruments, accompanied by small avalanches at pit.

O. H. Emerson

9.30 am. Rapid rise of steam at NE continues.
9.50 am. Roar.
9.57 am. Roar.
9.59 am. Loud roar.
10.34.30 am. Slight quake. Strong S–W tilt. Pit obscured by mist.
11.30 am. Steam cloud continues heavy.
12.37 pm. Spurt of steam N side.
2.38 pm. Roar.
2.50 pm. Roar.
4.00 pm. Part of pit in view, steam continues heavy.
4.21 pm. Loud roar.
5.05 pm. Roar.
5.09 pm. Roar.
5.11 pm. Roar.
5.15 pm. Loud roar for 1 min.
5.17 pm. Loud roar.
5.18 pm. Loud roar.
5.19 pm. Loud roar, reverberating noise for nearly 1 sec.
5.21 pm. Loud roar.
5.23 pm. Loud roar.
5.24 pm. Loud roar, faint rumble.
5.26 pm. Loud roar, gradually died down to be low continuous roar.
5.30 pm. Loud roar.
5.33 pm. Loud roar with one booming noise.

5.35 pm. Loud roar.
6.15 pm. No roar could be heard.
6.21 pm. Roar.
6.23 pm. Roar dying down. Dark gray cloud appears.
6.25 pm. Roar. Heavy steam cloud.
6.27 pm. Roar becoming louder in 30 sec.
6.30 pm. Heavy cloud NE side rising rapidly gray color.

R. H. Finch

May 26, Observers Hinkley and Emerson, Observatory
6.34 pm. Dust cloud NW side.
6.35 pm. Mild roar. Steam jet NE side.
6.38 pm. Loud roar. Rush of steam on NE side.
6.40 pm. Dust cloud NW.
6.43 pm. Steam cloud heavy.

V. Hinkley

6.51 pm. Strong 20 sec. roar preceded by slight 5 sec one.
6.52 pm. Short roar.
6.54 pm. Strong 15 sec roar.
6.56 pm. Short roar.
6.59 pm. Strong 10 sec roar.
7.01 pm. Small avalanche.
7.05 pm. Small avalanche, followed by short roar.
7.07 pm. 60 sec roar with thumping.
7.08 pm. 15 sec roar.
8.25 pm. Short roar.
8.51 pm. Strong 10 sec roar.
8.54 pm. Strong 20 sec roar.
8.58 pm. Slight 15 sec. roar.
9.19 pm. Slight quake.
9.25 pm. Moderate quake.
9.38 pm. Slight quake.
9.45 pm. Moderate quake.
10.13 pm. Short roar.

O. H. Emerson

May 26–27, Observer Durning, Observatory
10.26 pm. Moderate quake. Weather clear, wind E–SE.
10.33 pm. Roar at pit. Moderately heavy cloud over whole pit.
10.34 pm. Roar continues.
10.35 pm. Cloud rise is more rapid. Roar almost constant.
10.43 pm. Slight quake. Roar at pit.
10.55 pm. Heavy roar. Cloud quite high.
11.02 pm. Slight quake.
11.05 pm. Moderately heavy quake. No sound from pit.
11.07 pm. Slight quake. No sound from pit.
11.09 pm. Slight roar, cloud quite heavy.
11.12 pm. As seen from west porch of station, cloud does not seem to carry much dust.
11.22 pm. Roar at pit. Cloud still moderately heavy.
11.24 pm. Crashing roar. Avalanche.
11.28 pm. Heavy roar.
11.39 pm. Slight quake.
May 27
12.01 am. Weather clear. Wind S–SE.
12.06 am. Very slight roar. Cloud rise is slow and not heavy.
12.09 am. Heavy roar. Probably avalanche.

12.11 am. Very heavy roar.
12.15 am. Continuous slight roaring.
12.20 am. Moderately heavy roar.
12.28 am. Heavy roar. Cloud is very steady.
12.30 am. Roar continues.
12.32 am. Roaring is very heavy.
12.48 am. Slight quake.
12.48.30 am. Slight earthquake. Slight roar.
1.00 am. Cloud over pit very light.
1.15 am. Some tremor going on. No sound at pit.
1.30 am. No sound at pit since 12.48.30.
1.31 am. Roar continues 15 sec.
1.38 am. Slight roar.
1.45 am. Slight roar.
1.49 am. Long booming roar. Probably avalanche.
1.50 am. Cloud darker than for some time.
1.55 am. Cloud very light.

F. Durning

May 27, Observers Finch and Hinkley, Observatory and Halemaumau

2.18 am. Roar.
2.19 am. Quake.
2.23 am. Roar.
2.30 am. Pit obscured.
2.55 am. Roar becoming very loud in 10 sec. and gradually diminishing.
3.05 am. Roar for 10 sec.
3.20 am. Left for pit with V. Hinkley and Teddy, Dr. Jaggar's collie dog.

R. H. Finch

3.40 am. *Inspection of Halemaumau:*

Parked car and started afoot for pit. Road strewn with bowlders. Reached pit 4.05 am. and looked in but saw no glow. Crack by old parking place had moved since last dust deposit. Tested temperature with hand and found it close to boiling point on surface. 4.19.30 am. Felt quake preceded by and accompanied by rumble. 4.40 am. same, but rumble was louder. Both seemed to be E-W movements. 4.46 Avalanche SW side, also at 4.48 and 4.49. 4.55 a noise caused perhaps by a gas rush was heard. 5.00 left in car for Observatory. 5.25 arrived at Observatory.

V. Hinkley

5.42 am. Distinct roar. Pit obscured by mist.
5.46 am. Rather sharp quake.
5.47.30 am. Quake, made windows rattle but was not felt.
6.16 am. Mist clearing. Pit visible.
6.35 am. Mist heavy again.
6.41 am. Heavy steam cloud.

V. Hinkley

6.51 am. Roar.
6.59 am. Steam rising rapidly NE side.
7.21 am. Steam cloud thin.
8.00 am. Steam cloud heavy sometimes rising in 2 columns.

R. H. Finch

8.09 am. Slight roar.
8.22.30 am. Roar lasting 10 sec.
8.31 am. Roar heard again.
8.44 am. Another roar.

V. Hinkley

May 27, Observer Durning, Observatory

9.10 am. Crater clear of fog. Heavy steam cloud over pit. No dust.

9.22 am. East side of pit clear, west side heavy steam cloud.
9.26 am. Heavy roar.
9.30 am. Heavy roar at pit.
9.30.30 am. Steam cloud over whole pit. Light red dust cloud on NW.
9.31 am. Very heavy steam cloud center of pit, some dust.
9.35 am. Slight quake, spurt of steam N.
9.36 am. Avalanche on NNW.
9.39 am. Spurting steam on N.
9.44.30 am. Small avalanche on SE.
9.45 am. Small explosion cloud on NE side.
9.50.30 am. Small avalanche on NW.
9.51 am. Steam cloud heavy with dust on E.
10.13 am. Explosion dust and steam cloud on N.
10.20 am. Pit clear except small steam cloud NW.
10.23 am. Spurting steam and dust cloud E side.
10.29 am. Spurting steam and dust cloud on N.
10.31 am. Small dust cloud on NE.
11.00 am. Slow rise of steam on N.
11.15 am. Very clear at pit.

F. Durning

May 27, Observer Finch, Halemaumau and Observatory
Inspection of Halemaumau

9.00 am. R. H. Finch and Vern Hinkley left for pit. Took motion pictures of 8 ton bowlder, rock along road, the place where Taylor was found, and view of rocks looking toward S rim of crater. Approached rim of pit from SW. At S end of sand spit and for a considerable distance each side the ground was covered with small rock fragments and coarse gravel. On the sand spit side the gravel was on top of the last ash layer. A view into the pit was obtained at 10.45 am. The bottom appeared much the same as on the 17th, avalanche material covered the bottom and there was one long debris slope on the WSW side. The steam was rising from the usual vent on NE side. The relation of diameters of the pit seemed much the same as before the breakdown, much longer NE–SW than NW–SE. The odor of hydrogen sulphide was very noticeable so that both of us remarked about it. There was little or no steam in our vicinity. Some steam was rising almost from the foot of the talus slope on the SSW side.

11.50 am. Roar.
11.58 am. Roar.
12.10 pm. Small dark gray cloud arose at NNE side.
1.00 pm. Quake few seconds after 1.00 pm. N–S dismantled.
1.07 pm. Roar.
1.15 pm. Sharp quake. N–S dismantled.

R. H. Finch

May 27, Observer Durning, Observatory

2.32 pm. Roar, 10 sec.
4.05 pm. Gray cloud ENE rose rapidly.
4.18 pm. Avalanche NW.
5.12 pm. Spurting steam and dust cloud on E. Heavy steam cloud on N.
8.15 pm. Heavy mist obscured pit.
9.10.30 pm. Moderately heavy quake. No sound from pit.
9.50 pm. Fog lifting, very light cloud over pit.
10.09 pm. Moderately heavy quake.
10.30 pm. Slight quake.
10.32 pm. Moderately heavy quake.
10.34.30 pm. Moderately heavy quake.
10.37 pm. Slight quake.
11.40 pm. Slight quake.

11.46 pm. Moderately heavy quake.
11.51 pm. Slight quake.
11.59 pm. Very slight quake. Crater obscured by mist.

F. Durning

May 28, Observers Finch and Durning, Observatory

12.15 am. Moderate wind blowing. Pit obscured.
1.08 am. Quake, slight rocking motion for 4 or 5 sec.
1.10 am. Pit visible, heavy steam cloud continuous.
2.00 am. Cloud over pit thin.
2.10 am. Pit obscured and continued obscure at 4.35. The crater was full of fog and white steam clouds all morning.

R. H. Finch

8.11 am. Spurt of explosion cloud over E rim.
8.12 am. Explosion cloud continues to rise fast on NW.
8.13 am. Small weak explosion.
8.13.30 am. Spurting cloud SE.
8.14.30 am. Cloud growing soft on NW. Still hard on E.
8.16 am. Harmonic tremor 20 sec. dust continues heavy SE.
8.16.30 am. Tremor, continuous hard cloud working N.
8.19 am. Explosion, heavy spurting dust cloud over entire pit.
8.20.30 am. Cloud continuous, hard: heavy spurts on N and NW.
8.23 am. Cloud soft on N and W. East side moderately hard clouds continue to rise.
8.26 am. Spurting of steam and dust continues on east.
8.27 am. White vapor center of pit.
8.33 am. Heavy spurt of steam and dust on SE.
8.35 am. Steam continues to rise fast on E side, heavy with dust. Slight increase of dust over whole pit.
8.39 am. Steam continues to rise in spurts heavy with dust ESE side.
9.20 am. Clear steam rising to NNE, dusty to SE.

F. Durning

9.40 am. Puff of gray cloud from SE.
9.43 am. Puff of gray cloud from SE, the usual white cloud continuing at N.
10.01 am. Heavy spurt of dust and steam on E. Continuous steady rise of white steam on N and W.
10.10 am. Dust cloud on E, probably avalanche.
10.15 am. Dust and steam continues heavy on E.
10.25 am. Continued spurts of dust and steam on East.
12.00 noon. Cloud over pit very thin with only very small convection current above. It would appear that either the temperature or steam has diminished, or perhaps both. The whiteness of the cloud is perhaps now due to finely divided sulphur.
12.30 pm. Gray cloud arising SE and usual small white cloud NE.

R. H. Finch

May 28, Observer Hinkley, Observatory

12.38 pm. Small dust cloud E side. Seismograph recorded two shocks, first more pronounced. EW stronger than NS.
12.42 pm. Steam cloud heavier on N.
12.44 pm. Pronounced quake. Windows rattled. NS component dismantled. Amplitude on EW over two inches.
12.52 pm. Heavy steam jet N.
12.53 pm. Quake felt, windows rattled.
12.56 pm. Steam jet NE.
12.57 pm. Dust cloud E side.
1.35 pm. Dust cloud NE side.
1.46 pm. Jet of steam NE side.

1.48 pm. Small dust cloud NE side.
1.54 pm. Dust cloud NW side.
2.14 pm. Dust S well.
2.15 pm. Dust SE rose rapidly.
2.30 pm. Steam cloud heavier.
3.19 pm. Mist obscures pit.
4.05 pm. Mist lifts, pit visible.
4.18 pm. Steam cloud heavy.
4.29 pm. Pronounced quake.

V. Hinkley

May 28, Observers Durning and Hinkley, Observatory

5.05 pm. Steam continues heavy on north.
5.14 pm. Small explosion cloud on SE.
5.14.30 pm. Avalanche on NW.
5.15.30 pm. Spurting dust cloud on N.
5.20 pm. Mist obscures pit.
5.45 pm. Avalanche NW.
6.00 pm. Pit obscured by mist.
6.35 pm. Heavy white cloud all over.
6.40 pm. Small spurting dust cloud on E.

F. Durning

9.04 pm. Dark, but steam cloud quite plainly visible.
9.28 pm. Light mist blowing in.
9.33 pm. Mist heavy enough to obscure stars on horizon.
10.00 pm. Very faint cloud observed. Darkness pronounced with sky overcast.
10.36 pm. Small cloud over pit.
11.00 pm. Small cloud over pit.
11.24 pm. Conditions unchanged.
11.45 pm. No change noted.
11.47 pm. Very thin cloud noticeable.

V. Hinkley

May 29, Observer Finch, Observatory

1.00 am. Pit clear but little cloud could be seen.
4.00 am. Cloud heavier.
5.00 am. Cloud very dense over pit with but little or no dust on it.
5.17 am. Quake with distinct rumble and perceptible vertical motion. Much stronger E–W than N–S.
6.01 am. Avalanche cloud S.
6.25 am. Quake, N–S dismantled. Dust cloud from the S. Steam rising rapidly. Heavy dust clouds in desert.
8.00 am. Occasional puffs of steam rose rapidly, though a roar could not be heard on account of fresh wind.
10.35 am. Scarcely any fume or steam.
10.53 am. Small explosion on SE.
10.55 am. Steam and dust continue not heavy on SE.
10.56 am. New spurt of dust cloud on SE.
11.06 am. Explosion cloud on East side.
11.34 am. Dust cloud S side of pit.
12.45 pm. Steam puffs rising rapidly.
1.00 pm. Dust clouds thin, S side.
2.00 pm. Quake, N–S dismantled.
2.54 pm. Dust cloud N.
2.55 pm. Dust cloud N.

3.25 pm. Rapid rise gray cloud S.
3.57 pm. Dust cloud NW.

R. H. Finch

May 29–30, Observer Durning, Observatory
4.38 pm. Dust cloud N gray.
4.52 pm. Strong spurt of steam; some dust on NW.
4.59 pm. Small avalanche on East.
5.15 pm. Roar. Increase fume SE.
5.30 pm. Spurting steam cloud on N. Slight roar.
5.32.30 pm. Heavy spurt of dust and steam E.
5.45 pm. Slight roar at pit.
6.48 pm. Gray cloud from NE similar to gas rush or small explosion.
Blue fume arising from NNE as a thin wispy column.
May 30
4.26 am. Quake, both instruments dismantled.
7.00 am. Steam cloud rising higher than on 29th, though the wind velocity is less.
8.25 am. Jaggar, Finch, Emerson, Cody and Belknap start for pit.
8.42 am. Earthquake, and pit dust cloud. Both instruments dismantled.
8.43 am. Dust cloud E and NW.
8.44 am. Quake, N–S component, line of travel, set back ½ inch on drum. Tilt strong NE.
(Note—strongest quake felt here in long time. R.H.F.)
9.05 am. Drum set over at 9.05. Strong NE tilt.
9.10 am. Moderately heavy quake. N–S component dismantled.
9.12 am. Dust cloud on E and NW.
9.54 am. Small avalanche on E side.
10.24.30 am. Heavy roar from pit.
10.25 am. Avalanche cloud on NW.
10.26 am. Spurting steam on E and N. Continual rise of red cloud on NW.
10.50 am. Small avalanche on E.
1.00 pm. Steam cloud rising more rapidly than on 29th.
1.39 pm. Pit clear. At times no steam rising.
1.46 pm. Avalanche on E side.
2.18 pm. Roar at pit.
2.18.30 pm. Roar continues.
2.24 pm. Light dust cloud on E side.
2.50 pm. Roar accompanied by slight tremor. Dust cloud E.
3.41 pm. Slight roar.
3.44 pm. Heavy roar, 20 sec duration.
3.55 pm. Slight roar, 15 sec.
3.57 pm. Steam on E and N, heavy with red dust.

F. Durning

May 30, 1924, Observer Finch, Observatory
5.42 pm. Roar.
5.45 pm. Loud roar. No dust cloud followed except gray cloud at SE.
8.35 pm. Roar at pit, 30 sec.
10.25 pm. Avalanche on E side.
10.33 pm. Avalanche on N side.

R. H. Finch.

PART 4.—SERIES OF DEVELOPMENT SKETCH MAPS AND PROFILES OF HALEMAUMAU, CHECKED BY TOPOGRAPHIC MAPPING, 1917–1934

INTRODUCTORY STATEMENT

From the time the Observatory was first established in 1912 (Pl. 84a) provision was made for topographic mapping of the bottom of Halemaumau pit. In the publications there are sketch maps of the pit, and the maps of 1912–1915 were largely concerned with outlines of the liquid lava lake.

THE LAVA COLUMN

Beginning with 1916–1917 it became apparent that the top of the lava column inside Halemaumau pit consists of the whole circle of inner floor of the pit, sometimes enclosing the talus itself, and this entire circle, solid on the surface, with lava lakes as saucers inside, rises and falls as a sheath, encasing at least two wells and encasing connecting open or closed channels from well to well, by which the liquid lava circulates convectionally (Jaggar, 1917). Moreover this sheath extends down indefinitely and consists of a paste that encloses the wells and rises and falls so as to follow generally the liquid lava. It has been proved to have an internal temperature of about 900° C and to consist either of talus breccia cemented with lava or of aa lava which has been stirred and lost its gas. It is the refuse of the liquid glassy lava, which possesses the heat energy chiefly of its reacting gases and tends to freeze and half crystallize at a lower temperature on its bottom and sides, when circulating in a pit.

A flow of liquid glassy lava on the surface of the country rapidly stirred by the gases escaping from solution tends to crystallize at lower temperature on the bottom and sides of its self-made channel, in accordance with the sudden increase of viscosity that goes with loss of volatiles. The result is a narrow torrent highly liquid at a much higher temperature than the field of aa underneath and on either side, but the latter has also incandescence and is moving forward with a slow crunching creep. When this process is transferred to an upright shaft wherein only gas can escape, and the only subaerial flowage is across the talus or previously congealed bottom of a pit, when that bottom is covered some sort of convectional circulation is necessarily set up by the continued inflow, the continual loss of gas, the continual crusting of the surface, and the continual cooling by the walls of the basin and by contact with the air.

If such a fill were started by the lift of a bottom plug, the liquid lava rising on one side, flowing across the top of the plug, and down the crack on the other side might within its chilled shell make a glass tube shaped like an inverted U. If this process continued and the pit were filled to considerable depths, rising lava from the source well would be a standing fountain on one side of the lakes so formed, the horizontal portion would show a streaming of scum on the lake, and the sink-hole side of the U would be a downsuck of partly crystalline lava with remnant gas bubbles; these, accumulating, would escape upward periodically as rhythmic fountains. Meanwhile the lava of the depths of the lake would be receiving a shower of sunken crusts and would not have sufficient temperature to remelt them. The lava of the sides of the lake would congeal inward from the cold walls of the pit. The portion that would remain in liquid motion would have its size, shape, and rapidity of circulation controlled by the volume, temperature, and vesiculation of the oncoming foam from the source well in its adjustment to the sink-hole, to the freezing inward and upward of the self-made saucer, and to the volume of the shower of crusts piling up on its bottom. Tests by sounding and observation proved that the Halemaumau bottom was usually about 50 feet below the surfaces of the liquid lakes.

HALEMAUMAU A GLASS-BLOWING SYSTEM

The years 1917 to 1924 as here mapped (Pls. 77–82), after half a century wherein the liquid lava and gas were generally in evidence in some form of incandescence or flame at the bottom of Halemaumau, were distinguished by a live lava column, with its convectional circulation always present below in some sense. This means that the glassy tube encasing the circulation was also present. The glassy selvage of a dike is well known. Reverting to our analogy of a simple inverted U, and imagining source well, arch, and sink-hole to be so buried and viscous that the tube is flexible, expansible, and coterminous with the hypomagma below from which the circulation arises (Jaggar, 1920), an increase of volume and heat from the latter expelled vertically by an increase of escape of gas would carry with it the mobile tube. Wherever there is convectional rising and marginal semiconsolidation encasing the more liquid foam, there will be expansion and uplift of the semicrystalline tube within the confinement of the surrounding shaft. Thus the tube lava must rise within the confining blow-pipe.

The border magma of the deep tube system, then, may be imagined as though the volcano were a glass blower with his blowing pipe directed upward, his clot of lava glass on the end of the pipe, and his breath a vesicular foam at 1200° C. The vesicular foam and the glass clot are the same substance. The glass clot is the semicongealed shell over the vesicular foam. Both emerge from a deep magma, surcharged with a gaseous solution, which presumably by release of pressure through a fracture in the top of its container vomits up its gases as bubbles. It is entirely a matter of speculation how deep within the volcanic edifice is the age-long maintained body of this hypomagma or what is its shape.

With lava under tumbled debris in the shaft at the bottom of Halemaumau, and an eruptive rising about to begin, the lava is an incandescent ferruginous glass impelled upward by expanding vesicles. The vesicles contain reacting fixed gases such as hydrogen and carbon dioxide. The incandescent matter percolates through the crevices and up to the bottom of the pit. It immediately forms shells of glowing glass and of partial crystallization within the crevices and all around and over the pool. Selection of paths of least resistance within these shells ensues. Congealed crust is heavier than liquid beneath, and wherever it is broken into slabs over increasing volumes of liquid these slabs sink to the bottom and form a pulp that is added to the sharply differentiated bottom. The bottom and sides of the saucer at 900° C differ in gas content, crystallization, and viscosity from the highly mobile liquid at 1100°–1200° C, maintained mobile and more fluid within its hot insulating shell by its vesicularity and by the oxidations and other exothermic reactions of its gases.

DIFFERENTIATION OF AA

GENERAL CONSIDERATIONS

This differentiation in basaltic foam at the time of extrusion on the bottom of its container or on overflowed country rock is of prime importance and has not hitherto been understood in the geology of volcanoes. The smooth, glass-topped pahoehoe or ropy lava and the rough, sprouting, and broken aa or scoriaceous lava have been taken for granted. Some argument has been expended in accounting for aa (Daly, 1911; Washington, 1923). This debate the author has taken part in and only gradually has he realized its implications. The physical chemistry of Hawaiian basalt melted and stirred (Jaggar, 1917; 1920; Emerson, 1926) as in a Bessemer furnace by jets of burning carbon monoxide, hydrogen, and sulphur vapor has not been investigated. Emerson's experiment of melting it and stirring to produce the more crystalline scoriaceous form is of far-reaching importance. But stirring by a hydrogen blast has not been done.

The writer distinguished "aphrolithic" aa from "dermolithic" pahoehoe (1917) and later recanted to call aa "clastolithic" (1920) or "dendrolothic." "Aphrolithic" appears quite satisfactory. Finch (1933) has distinguished "block lava" for silicic types that are broken without the sprouted, arborescent, scoriaceous character. Emerson's paper, backed by experiment and microscopical petrography is the best that has been written. Emerson accented crystallinity stimulated by stirring but did not mention gas stirring. This was mentioned by Jaggar (Volcano Letter No. 281) as "sugaring due to stirring"; a more complete analysis of conditions was made by observation of the Mauna Loa eruption of 1935 (Volcano Letter No. 442) described as follows:

PAHOEHOE MECHANISM

> "This melt was essentially a foam impelled both by gravity and hot gas expanding within it. The tunnel system created by its crust made a pipe leading from the source elevation on Mauna Loa to the front of the flow 2,000 feet lower. The froth stream secreted a glassy skin over itself as a roof; this is pahoehoe lava.
>
> "Such a torrent in a tunnel, makes an adjusted pressure system connected through the rift opening of its source with the central foam column in the crater shaft, inside the mountain. The open crater pit at the top of the mountain sends up the fume of burning gases from internal fountaining. Such is the relationship of the crateral vent of first outbreak to the lower rift vent after the most violent gas emission has ended. The opening of the rift is probably a tumescence phenomenon occasioned by the powerful thrust and expansion of the semi-congealed marginal lava within the shaft system, after it has lost part of its heat through escape of gases.
>
> "When the stage of pahoehoe outflow from the rift is reached, the adjusted pressure system causes the gas-heated foam to hold a certain level in the shaft and the flowing foam in the pipe system outside pours down a crusted-over river bed under both hydrostatic pressure and gas pressure."

The charge of gas in solution remains in the lava in decreasing amount, and possibly in different proportions of the constituent fixed gases, from the hypomagma inside the earth to the last congealing tongue of the front of a lava flow. Eruption is the phenomenon of discharge of gas by permitted vesiculation. The most obvious cause of such permission, the same being graduated and cyclical, is release of an age-long pressure upward of the hypomagma itself under a volcanic system and the yielding of the edifice.

AA MECHANISM

The gas-charged melt of a vent is stirred and rapidly crystallized both by effervescing and rapid flowing. If it flows with gases rising from within it, it is heated on top by the gases and within by crystallization, and it is cooled and solidified chiefly on the bottom by contact. The hot gases incessantly escape by drawing out filaments and without forming bubbles, and the solidification proceeds from the bottom upward. This solidification takes forms of sprouting determined by crystal groupings, and no time is allowed for the separating out on top of a glassy foam. The sprouted crust is aa.

AA EMERGING FROM PAHOEHOE

Near the vent, however, glassy foam is formed in enormous quantities and makes the basaltic pumices, Pele's hair, Pele's tears, and heavy ropy folds of coarse pahoehoe which is always characteristic of the source region of any flow. The first rapid streams on steep upland slopes have the highly stirred crystallizing material of aa pouring out from under this tangle of glassy membranes only a short distance down the mountain from the source pahoehoe, and the solidifying from there to the lower end of the first lava torrents proceeds by the aa process.

PAHOEHOE FLOW OVERTAKING AA

When the gas stirring lessens, and the rate of flowing decreases, glassy bubbles as at the source region can form and rise to the top, and the glass-topped flows progress past the aa fronts. These bubbles make a layer of many membranes of glass which stretch over the expanding and advancing liquid. Cooling proceeds from the air downward, and a glassy crust confines the melted stuff within. In this pahoehoe condition we have exactly the same liquid melt under the skin tending to crystallize, but it fills a pipe. This pipe itself imposes restraint by pressure on the escape of gas from solution; and the formation of new glassy membrane over the liquid pushing out as toes under the skirt of crust at the front imposes a restraint by pressure on the speed of flow of the liquid. These two restraints by glass shells enforce a relatively constant adjusted pressure, and the vesicular crust now has the effect of a heat insulator and gas-tight bag and keeps the melt inside from radiating heat and so losing its liquidity. As the gas does not escape, except through fountains near the upper vent, the whole system preserves the heat of reaction, and so a lava tunnel (Pl. 7) will hold a brilliant yellow color of incandescence, even when the liquid river inside has lowered its level somewhat and through collapsed windows is sucking in oxygen to unite with the gases and the glazes to keep temperature high.

There are three important corollaries to this heat argument—namely (1) Pahoehoe and aa lavas are exactly the same substance; (2) the internal crystallitic liquid or paste under any pahoehoe crust or in any tunnel is quite competent to become aa lava if allowed to flow in the open through a ruptured shell or down a slope steeper than the glass-blowing gas-bag process permits; (3) the only mechanism on a flat grade which could slowly carry a lava flow 40 to 50 miles is pahoehoe tunnel making, for that insures retention of heat and liquidity. After the first rushing aa flows have stopped, the source flows of pahoehoe pass them and push far.

The equilibrium of the interior of an adjusted lava tunnel is maintaining a nicely balanced example of the glass-blowing process at its front, where the numerous toes are bellying forward and encasing themselves in membranes of vitreous consolidation. The equilibrium of such a tunnel near the source is obviously such that if a large section of its roof is suddenly destroyed by earthquake or bombardment, and cold air is let in, rapid congelation of the internal fluid will ensue.

MAGMATIC DIFFERENTIATION OF BASALT

GENERAL STATEMENT

This long explanation of the aa and pahoehoe process is quite necessary because of the evolution of opinion that it represents, and because it stands for a form of magmatic differentiation that is fundamental for understanding the liquid lakes, overflow platforms, crags, and islands of Halemaumau, hereafter shown as maps and sections. The lakes and lava flows of Hawaii are differentiating the magma that rises in the deep region into three substances—namely, volumes of burning gas at highest temperature, spouting floods of vesicular glass at next lower temperature, and encompassing shells of incandescent crystalline paste at still lower temperature. Lava emission creates a blow-pipe system from the deep region upward wherein the gases are impelling, heating, and liquefying the foam, the border selvage is creating a voluminous mantle of differentiated mobile crystalline paste inward from the contacts and top of the lava column, and the bursting and burning of the bubbles at the surface creates in relatively minor volume the fountains, lakes, and liquid streams that are confined, within contact shells, or spread-out fields, of the crystalline paste. In Halemaumau pit and far down the shaft this marginal paste is the most potent and voluminous moving unit of the lava column; in any lava flow the extensive paste is the large low-temperature field body flowing slowly, crusted over but pasty within, that lies under and on all sides of the distributary streams that make channels and tunnels within a widespread sheet of slag.

IMPURE SEDIMENTS IN LAVA

The hypomagma is the deep source fluid, presumably a glass; the epimagma is the contact sheath of crystalline paste; the pyromagma is the glassy foam (Jaggar, 1920). By contact sheath is not meant glassy selvage; many intrusions have none. In 1920 I attributed much of the quality of the epimagma to impurities due to engulfment of talus, crusts, and of what I called "sediment" the refuse left by a gravitative shower of debris when effervescence of contained gas had expended itself. Both the epimagma of Halemaumau pit and of lava fields is in many places basic breccia. In other words aa flows and broken Halemaumau crags appear full of dirt.

However, it seems likely that Emerson's explanation of true aa scoriaceous sprouting crust (Pl. 73d) as due to internal stirring that stimulates rapid crystallization of magnetite, feldspar, and augite is nearer the truth than Jaggar's suggestion of "granules of sediment flowing like cheese without inflation." Jaggar's statement "the swift and long Hawaiian flows are pahoehoe at the source and aa below" is incomplete: rapid aa is intensely liquid and full of gas and in 1859 flowed 38 miles in a week; slow pahoehoe may be a rapid, potential aa liquid in its tunnels, but with spread-out front of many partly glassy toes, that goes about 40 miles in 9 months (1855 and 1881) and passes the shorter and earlier aa flows of the same year.

Possibly remelting by gas in the tunnels adds glass to the liquid melt, for glazes are remelted on the ceilings of such tunnels (Pl. 7b, e). The gas differentiate of the magma is the only ingredient at the surface capable of melting solidified lava; its temperature is 1300°–1400° C., the pyromagma 1100° C., and the epimagma 900° C. These temperatures have been measured (Jaggar, Thermal Gradient, 1917c).

PYROMAGMA, EPIMAGMA, AND HYPOMAGMA

Reverting to the magmatic differentiation in Halemaumau pit, the succession of maps and sections reveals that pyromagma and epimagma lift and lower more or less together. When, after a lowering, the previously lowered craggy epimagma is lifted very rapidly, as in December 1919, it must be conceived to be made up near the surface of crushed rocky matter partially engulfed, shaped like the mould of the interior of a funnel, and lifted on a stem of epimagma from the depths.

This epimagma in the depths brings to light a new consideration. No one who has watched, with years of measurement, the detail of semiconsolidation of the bottom and sides of shallow Halemaumau lava pools, and the rising and lowering of upright pencils of this substance in much greater volume than that of the liquid in the wells, can doubt that this semicrystalline substance extends downward.

This means differentiation and semicongealing of the basaltic magma in the depths. Crystallization is not usually called differentiation; but it is so if a gas-liquid-melt in small volume compressible and with vesicles expansible separates in wells within a large-volume crystalline paste free of gas, less compressible and much denser. The pyromagma somewhere in those depths is escaping from the hypomagma as gas-charged foam. The crustal edifice above has yielded to tumescent force or tectonic tensional force, and a crack permits the foam to penetrate the crust toward the surface of the earth.

At once contact cooling takes place, expansion cooling is permitted, conduction (very slight, Daly, 1911, p. 71) into the walls of the crack occurs, and a glassy or semicrystalline paste forms a bulb or shell of glass-blowing mechanism upward.

This was seen in action 60 feet down cracks in the outbreak of the Kilauea flank southwest in December 1919. The lava rising up the crack was covered with black vitreous skins, was freezing against the walls of the crack, and was thereby leaving below a semicrystalline composite dike, with froth or foam rushing up the middle and an indefinite volume of its crystalline residue left on the walls. This foam spouted out on the surface, built up a slag heap with horizontal dimensions in miles, trickling with liquid lava on the surface, but consisting inside of a body of heavy crystalline paste, which occasionally burst forth as short protrusions of stiff aa lava. Meanwhile long extrusions poured down the mountain as narrow outflows, at first rapid aa, later overtaken by slow pahoehoe. It was clear that this crack extends through Halemaumau pit, that the tunnel connection along the crack joins Halemaumau to the outflow 6 miles away, and that it extends through Halemaumau pit, and at depth is lined as a dike with the crystalline differentiate of the pyromagma. In the desert over the dike vents of Mauna Iki, temperatures of 300°–400° C. were maintained for 10 years. Doubltess at the end of the eruption, when the fill of this crack closed all vents in the slag heap in the desert (Mauna Iki) and backed up so that the only remaining activity was in Halemaumau pit, it may be assumed that a continuous dike occupied the crack. This dike was afterward seen on the Halemaumau walls, on both sides, in the line of the rift. Echelon surface breaks appeared, but the big tunnel in Halemaumau was on a single crack (Pl. 45b).

With the epimagma extending downward, gases play an important role in connecting volcanism with the primary magmatic chambers, and the contact refuse products of vesiculate glass rising up crustal fissures are crystalline intrusions. The well-known basaltic dikes of Hawaii are not vesicular and show nothing remarkable or particularly glassy in their middle zones, any more than aa flows consolidate glassy in their frozen streams. Dr. Stearns reported and photographed a dike in Maui showing aa texture (personal communication).

Basaltic dikes go geologically deepest in the earth crust. The so-called trap dikes cutting most ancient formations may have had pyromagma gushing up their middle zones to feed volcanoes at the surface of the earth. What about andesites, rhyolites, monzonites, diorites, and all other prophyries? The profundity, uniformity, recurrence, and world distribution of trap dikes have been used as arguments for a basaltic substratum (Daly, 1911, p. 51; 1914, p. 165; 1933, p. 42). If this argument is sound, there appears to be reason for thinking that Hawaiian lava rises from depths of 50 kilometers or more. If the wedging action of such magma makes earthquakes, this conclusion is verified by the occurrence under Hawaii not infrequently of earthquakes determined to be 30 miles or more deep. Whether substratum or igniseptum, the argument is the same.

The author would warn the reader that the following are selected maps of typical or critical times in series, and the descriptions are not mere repetition of the Observatory Bulletin. He makes no apology for introducing anywhere, if it is relevant, a geological discussion. Where there are such oceans of detail as reside in the Observatory record books—these maps are selected and finished from among hundreds of surveys—it is discouraging and difficult writing to have to present new evidence, from experiment and observation mostly unfamiliar to geologists and geochemists, which goes against current theories of magma and the earth.

The overpowering revelation by sounding in 1917 that liquid glassy lava (pyromagma) is the smallest part of the lava column, that the stiff crystalline paste (epimagma) is the greatest part, and that the "floating islands" of Dana are physically impossible entails consequences that are here developed (Dana, 1891, p. 60, 98, 176). Such a simple phrase as "there had been a weekly period" (heading hereafter "map of January 7, 1924)" illustrates the large resources for future study of the records of the Hawaiian Volcano Observatory, where seismometry, surveying, and photography colloaborated. It will take a special investigation and tabulation to explain the measured facts of that rough statement "weekly period." It is not within the scope of this illustrative memoir on craters, except to such extent as the reader may take upon himself to examine the dates of surveys on diagrams (Pls. 75, 76).

MAPS AND PROFILES OF HALEMAUMAU, 1917

GENERAL STATEMENT

The year 1917 was a time of much experimental work (Jaggar, 1917), and by way of the northeast ledge of 1894 it was possible to reach the floor of the pit, to walk over the crusted epimagma, and to thrust steel pipes and gas-collecting tubes into appropriate lava pools and flame holes. For 5 years after this the lava lakes were more or less accessible, and this was a time of incessant measurement and collection of specimens and data.

In Plate 77, four maps and sections of 1917 are shown of January, March, May, and August, respectively, to exhibit for a single year the meaning of intake and outlet wells of pyromagma in epimagma, the relatively small volume of pyromagma, and the upturning and fluctuation of the crags, produced from the heavy shells of overflow lava on the epimagma; arrows indicate the streaming surface currents on the liquid lakes.

The maps are reduced from transit surveys of 100 feet to the inch, the meridian through the north station 155° 17′ 8″ W, the parallel of latitude through the east station 19° 24′ 33″ N. Pyromagma open pools, feeding wells, and sinkholes are white. The relief map is expressed in each case as though Halemaumau were photographed from the air at night. The lower outline and profile exhibit the line of section, and the vertical section is the same scale as the map.

MAP OF JANUARY 12, 1917 (Pl. 77 a)

In previous publications (Jaggar, 1917d; Bulletin, 1917, p. 83) it was shown that this condition of Halemaumau was derived from a simple angular pool of June 1916 (Pl. 15) that filled the hollow of a cup of talus left in the bottom of the pit by the rapid collapse of Halemaumau June 5, 1916, following the Mauna Loa eruption of that year. Lava pouring back into the pit had bubbled up at the west a short distance from where the west pond is shown here in map and section. The pool of 1916 thickened to paste on its bottom and border, and from a depth of 673 feet below the rim of the pit June 6, 1916, the surface of the lava column had risen in 7 months about 600 feet and had created the great western crag mass now 65 feet above the lava lake. This structure had begun its career as a fuming peninsula, partly a lifted shoal or island, which at first had been only a cracked and swelling marginal bench of the large lake oval of June–July 1916. Then came a succession of lava floodings and bottom upliftings that permitted two pronounced source wells to appear at the west, as mapped. From the northern one a torrent poured around the crag mass northeastward (Pl. 14d) to cascade down a sinkhole northeast. The southwestern source well, now represented by coves at the western ends of the two southern arms of the lake, sent two streams eastward to sinkholes south and southeast.

The map of January 1917 may be thought of as three lava flows that poured eastward from vents at the west in June 1916, lost gas and heat, and merged with sinkholes east, at the border of the underlying cake of talus south, east, and northeast. There had been a body of lava in the pit less than 300 feet down in the spring of 1916, and when this lowered suddenly June 5, 1916, it immediately recovered, so that there was a column of epimagma ready to push up the cake of lowered matter. If a cake V-shaped in section is pushed up and the liquid wells up most strongly at the west, it can easily establish convectional sinkholes at the east. Thus we may imagine that the underlying body of epimagma is inherited from 1915 and that the three streams across the bottom end respectively at the south, east, and northeast sinkholes which are shafts under the floor margin. The southern line of crags, the middle line making the long peninsula, and the big crag mass extending across the lake to the east crag all represent accumulations of epimagmatic relief between streams. The streams begin with tunnels and end with wells. Tunnels are nothing more than frozen-over streams. Probably the south wall-crack pond shown is a tunnel or branch of the southernmost well. The positions of the other two are indicated by the arrows pointing against the eastern bank. The situation of these holes is developed as actual ponds in the map of May 28. The profiles of January 12 and March 2 diagrammatically indicate the source well at the left and the sinkhole at the right (Pl. 77).

DEPTH OF THE LAKES

During the great rising of 1916, the crags and islands were always present, the source pond preserving its integrity within the backslope of the western crag mass while the latter was swelling up as a sector of tumefying epimagma with its uplifting point near the center of the pit. The whole epimagma was rising as a paste in which the wells were maintained, while on top of it shallow streams across it maintained channels about 50 feet deep that merged to form the large lake. On several occasions in 1917, with the map approximately as shown for January 12, steel pipes were thrust over the rampart and down into the liquid lake and stuck on a pasty bottom 50 feet down (Pls. 21–23).

This bottom was vividly revealed in February during periods of recession of the liquid lava while the epimagma remained high; at about the depth indicated, 50 feet, a sinkhole pot 60 feet across appeared in the bottom of the south arm, with the torrent from the west cascading into it through a glowing gorge of fiery erosion and gigantic flames shooting up, and a similar cascade appeared 50 feet down under the rampart at the edge of the lake northeast, with the liquid lava of the north arm pouring over submerged harder matter into it. The differential lowering confirmed the soundings in proving that the lake at its upper shore line was about 50 feet deep and all this adventure revealed a shallow lake bottom with small wells and vertical lake margins coated with a glaze of slag. Some of the southern crags changed from islands into parts of a single peninsula as the liquid lowered, showing that no question of flotation or of "floating islands" can be raised. All the islands that we have ever measured and mapped in evolution are protuberant shoals or bars of a shallow bottom, and the entire mass of crags, floors, islands, and bottom rises and falls measurably with the main lava column. Even the lips of the wells rise and fall differentially to the liquid within them. The liquid at the east was usually a few feet lower than the liquid of the source wells at the west, and the crags rose or fell differentially and showed definite tilting.

UPPER EPIMAGMA HETEROGENEOUS

DESCRIPTION

In no case, however, did such a heavy hill of epimagmatic rock show signs of foundering gradually in the substance of the epimagma. The upper epimagma was lighter than the deeper epimagma. In many cases the liquid rose and drowned the crags and added new layers of epimagma to the floors. Thus the epimagma of the pit filling, by 600 feet of elevation, during the 7 months preceding this map, achieved mass uplift of the epimagmatic paste, with measured indication that where a shell of crust was involved the central region rose faster than the cemented and frictional margins. This was the main cause of tilted crags.

There were also overflow layers produced by the pyromagma flooding the floors and imprisoning the tilted crags and islands of former floors. These vitreous shells are necessarily lighter than the crystallitic paste. How this stratified matter, as well as the talus of temporary engulfments, becomes incorporated in the epimagma several hundred feet down, so that the whole column behaves like paste at a uniform temperature, is a matter of conjecture. There is some kind of gas-heat percolation, and there is certainly differential flow in vertical pencils of the epimagma. The discussion of observations relevant to this question has appeared from time to time in the Bulletin of the Observatory (Vol. IX, Nos. 3, 9, 10).

The measurements of January 12 that are shown determined that the lake was 87 feet below the south rim of the pit, and indicated a rise of 14 feet in 8 days. The crag at the east end of the southern peninsula stood 49 feet above the lake, the east crag 52 feet, the southwest crag 45 feet, and the western crag mass 65 feet above the liquid. The lake was about 800 feet long from northwest to southeast and 700 feet wide opposite the west arm.

The lake was 6 to 10 feet below its bank, first subsiding and thereafter rising with some inrush at the southwest cove and churning in the grotto there. There was southward streaming from under two arches in the west half of the south peninsula. A sluggish pile of pahoehoe lava was making incandescent toes over the crust of the west pond. There was occasional heavy bombardment in the northeast and southeast rampart grottoes, and sometimes very heavy blowing fountains in the middle of the north cove. Two heavy falls of spatter-bench materials tumbled into the lake at the southwest.

The lava lake had been rising for a week about 2 feet a day with overflows from time to time and lava welling up through northern cones on the floor. The crags had risen at about the same rate as the lake. During the week following, the rate of rising increased, and the upper portions of the large crag mass were in full view seemingly clear of the rim of Halemaumau as seen at the high northeast edge of

Kilauea Crater; by actual measurement the crag mass was only 8 feet below the rim. The rising was remarkably constant with overflow of the north and south ramparts (lake shore) and uplift of the east and west crags.

MAP OF MARCH 2, 1917 (Pl. 77 b)

From February 3 to March 2 there was subsidence of the lake of about 80 feet and increased relief of the crags (Pl. 75b). The funnel shape of the outer wall of the pit had caused the lowering epimagma to leave an encircling bench. The sinkhole at the south into which the western stream cascaded had now determined an arrangement by which the inbreak toward the center of the southern peninsula had opened a passage through the archways at its western end, so that the lake began to exhibit three arms radial from its center. With the excess lowering of liquid, new shoals extended the eastern and southern crags toward the center.

The eastern development had been an extraordinary transformation on February 18, when the east crag in breaking away from the bench had subsided 30 feet; while opposite it, out at the lake shore, the low flat point had risen suddenly 40 feet, a flat-topped mass, with its summit an oval table 100 feet long. Its upper edge showed the spatter rims of its former lake-shore position for 6 feet in horizontal bands, where for 35 feet below the raw reddish wall was of aa lava and was grooved vertically by scraping against the sides of the opening in the crust of the epimagma; it had presumably risen rapidly like paste from a paste tube, at the crusted margin of the lake, as a red-hot mass and without giving time for any spatter marks to form. This disturbance unseen had happened at night, but it was clear that single pencils of epimagma can rise and congeal to form aa.

The measurements for this map were made at 10:00 a.m., March 2, showing depression of the lake below the rim of the pit to be 120 feet in the southeast channel and 114 feet on the extreme west margin of lake. The reference was to a single east station. (Bulletin Hawaiian Volcano Observatory and therein the original surveys; *also* station elevations in maps of Plates 77–81.) It is the purpose of these descriptions to show the reader maps and sections not in the original Bulletin and to discuss principles while avoiding detail. The outline given shows how crusting and solidifying masks important features, the names change, an island today is a peninsula tomorrow, a pond or well always present below changes to a blowing cone, and the endless rending and shifting of the epimagma changes the appearance of coves and crags and ponds. A single visit to Kilauea in action gives no conception of secularly important source wells, sinkholes, tunnels, sectors, and progressions for each year. Only a permanent station can map and distinguish the essential things, for Halemaumau in action is a lava flow restrained by a container. It is a perpetual experiment by Nature in magmatic synthesis and differentiation. Therein lies its great value. There was thus a downward slope of 6 feet to the surface of the lake from the source region at the west to the inrush at the southeast grotto. The shore bench was 11 feet high above the lake, the east crag 81 feet, the new east table 59 feet, and the western crag mass 83 feet above the lake. The preceding week had shown subsidence of 14 feet with a tendency to collapse of the marginal bench that had stood at and preserved the January level. Cascading into pot holes at the edge of the lake was seen northeast and southeast. The fumes were sharply sulphurous, and locally the vapor had increased in visible density. The week following this mapping the lake rose 15 feet, accompanied by concealment of the cascading into border sinkholes and by the building of a lower bench all around the lake, which the latter occasionally overflowed. The crags remained stationary.

BURNING GASES

A note made on February 28 was to the effect that when hardened spatter rims fell into the lake immediate boiling was produced apparently due to the action of air, confined in the vesicles of the hardened lava, and perhaps to the oxygen acting on the combustible gases of the liquid melt. In the evening lazy blue flames like burning alcohol played at some southwest chimneys, the larger being a pot 6 feet in diameter. A spurting blue flame under pressure rose from the bank of the lake beside a filagree glowing cone southeast; also brilliant glow, pale flame, and yellowish fume rose from the northeast cascade pit, just as on February 14 there had been an immense banner of pale flame over the south cascade well 60 feet across.

Such detail shows the permanent presence of burning gases, which the nineteenth-century observers considered exceptional. The Mauna Loa fountains have gigantic jets of flame, masked by incandescence lighting up fumes. The descriptions from the informers of Dana, describing columns of liquid jetting up, missing the significance of fumes and vesiculation, and wholly minimizing gases, have held back volcanic geology for a century. Gases that burn are not steam (Jaggar, 1940).

MAP OF MAY 28, 1917 (Pl. 77 c)

The relief differences of the profiles are deceptively small because they are drawn to the horizontal scale of the maps. This third map of 1917 records a great rise, the highest of the year for the liquid lava. The low level of March 2 increased the height of the crag mass relative to the liquid (Pl. 75b), and now on May 28 at a high level the liquid lava greatly gained on the crag (the absence of outlined columns on May 25 does not indicate absence of crag, but merely absence of crag survey). The maximum height of the true lava column (epimagma) above the rim of the pit was registered three times at almost the same value during 1917 (Pl. 75b), while the more erratic small volume of pyromagma fluctuated widely in its effervescences. This comparative stability of the epimagma as a measure of the height of the true lava column, with slow tidal fluctuations changing as a steady moving paste, was confirmed in the hour-to-hour tide survey made in 1919 and analyzed by E. W. Brown (1925). (Jaggar, Finch, and Emerson, 1924.) Brown rejected the frothy fluctuation of the lake as too erratic for tides. The following is the description of Halemaumau progress at the time of the May 28 survey:

The week ending Friday, June 1, 1917, was marked at Halemaumau by gorgeously brilliant spectacles of rising, and very rapid uptilting of the inner crags. All these crags came into full view from the Volcano House on the northeast rim of the greater crater, recalling the scene picture in the early 1880's (Gordon Cumming, 1883, drawings) when there were similar crags above Halemaumau. The overflow level on the southeast inner bench of Halemaumau on May 31 broke all records since 1894, reaching a height of only 22 feet below the rim of Halemaumau, the lake itself being 2 feet higher (because the lake surmounts an inner slag-heap). Fountains and blowing cones spurted so high as to be visible from the Volcano House. The pit as seen from the west bluff of Kilauea was remarkably like a moon crater, showing outer and inner concentric cracks and ridges, irregular peaked inner crags, but differing from the lunar rings in exhibiting an active glowing lava lake. The end of the week showed a sinking of the lava, expectable just before the solstice.

Measurement at noon May 28 made the depression of the southeast bench of overflow 28 feet below the rim, and in contrast to this the bottom of the northeast depression was 59 feet below the rim, and the 1894 northeast bench valley was 65 feet below the rim. The overflow center was thus excentric. The depression of the lake at the moment was 35 feet, and above its mean surface the heights of the crags were as follows:

	Feet
Older east crag	10
West crag mass	47
East point crag	45
Southeast cone (lava pot)	12

During the week ending June 8 the liquid lava subsided to a depth of 75 feet below the rim, reaching this low level in 3 days. June 3 showed lake depression of 78 feet, although only the day before the crags had stood at their highest elevation well above the edge of Halemaumau. Beginning June 2, however, the crags subsided gradually for a week, the lake apparently compensating this, perhaps by a rising of its pasty bottom lava, for the liquid surface fluctuated but little and rose slightly at the end of the week.

The action on May 28 made short floor overflows east and west in the morning, followed by 5 feet of forenoon subsidence and then recovery. There was violent bombardment of the east bank, and the streaming was eastward as usual. A northwest table crag had recently appeared (not shown by the draftsman for May 28; *see* map of August 3, and photograph in Bulletin, June 1917), and this was higher, as were the inner crags. One of the inner flows of the morning had swept over the southeast bench northward to the base of the 1894 ledge. At 1:00 p.m. the west cone, an open oven facing westward (west pond locality) was vomiting out lava which spread over the floor to the north and south, and these flows extended themselves during the afternoon. A northwest cone had built a high driblet heap.

The sudden lowering May 28, 1917, was inaugurated at 7:15 p.m. by a tumble of benches with clouds of dust and gas brilliantly illumined by multiple fountaining. The lake had subsided 15 feet in the late afternoon, and a readjustment of the epimagma lifted the central crags and possibly opened crevasses that temporarily lowered the lake. In the evening a profound lake basin with a cavern facing east at lake level between the two crags of the southern peninsula appeared as a glowing vault (Photo 3; Bulletin, vol. V, no. 5). There was high incandescence and rapid current from the center into the east arm. A southwest crag had toppled over northward. The inner cliffs around the main lake were 40 to 90 feet high. Some of the crags had risen suddenly at the south and east, and a lava pond opened at the northeast. The western crag mass rose with westward tilt so that its northeast peak had suddenly become its summit, and the spatter markings along its base on the lake side were 40 feet above the shore. The lower part of the wall around the southeast arm appeared to be aa lava, while higher up the cup was horizontally banded with spatter lines.

By noon the next day, May 29, the lake had recovered, was brimming level with its usual shore, and big overflows swept from the east side of the lake into the northeast depression (Pl. 19). The lake rampart is always higher than the ground behind it. High spatter heaps were built up 15 feet at the west-pond locality, flinging up umbrella-shaped bodies of melt with a gulping noise and a bell-like ring. These spurts were plainly seen at the Volcano House, other cones were building at the northwest, there was strong gas pressure in the pyromagma, and floor overflows occurred all around the lake. All this agitation was introductory to the depression that was to follow.

A feature shown by this map, repeated in maps of succeeding years, is the division of the lake into three radial arms, marking a tendency for the epimagma to swell and rupture in the center and divide its crust into sectors. The lake adjusts itself to the ruptures, and the sectors lift into crags. There is a crude resemblance to isostastic adjustment in these crags, by reason of the tendency for the overflows to fill and weight down the wall valley and so squeeze the underlying epimagma toward the center. Frequently there is a correlation between large encircling overflow fills and central uplift of crags immediately afterward; the spatter lines of lake-shore levels dip centrifugally from the pencil of uplift (Pls. 40b, 43a) with the higher ones the steeper, as though the shore benches from center outward had been raised in a series of jerks. The center of rising is not always at or near the center of Halemaumau. Great crises of epimagmatic rising and hot pyromagmatic gushing were developed excentrically in later years, sometimes over the wall crack itself (Pl. 33).

MAP OF AUGUST 3, 1917 (Pl. 77 d)

Inspection of Plate 75b shows that again the lava column of Halemaumau had suffered a lowering. Again the liquid lava had lowered faster than the maximum height of the lava column represented by the topmost crag. A notable event of these months was the rising into dominance of the central crag, near the tip of the south peninsula, and the subordination of the western crag mass. Thus on June 8 the west crag mass was 64 feet, and the central crag 49 feet above the lake; on August 3 the old crag mass was 46 feet, and the central crag 74 feet above the lake. For the remainder of the year this was the datum crag for the top of the lava column. The south sector had increasingly pushed up into prominence during the year, as had all three sectors during the lowerings which had increased the relief of the epimagma that was retained in the next rising.

During the week ending August 3, 1917, the lava column was maintaining its level with very slight subsidence. On August 2 there was a magnificent breaking up of some of the benches; the east point collapsed, other crag blocks and shore benches fell, and the lake seethed with many hundreds of fountains. The central peaks adjacent to a collapsed cavern south of them rose bodily about 10 feet and developed a sharp pinnacle on the eastern side. The whole movement was a readjustment of craggy crusts of the epimagma, undermined by tunnels northeast and south which had recently made cracks and flaming chimneys above them. The hot gas blowpiping through these cracks finally opened them so that the weights of crust blocks were shifted, and the pasty under-lava flowed toward the center away from the heavy outside floors and lifted the central peaks. A straight chasm was left in place of one of these caverns.

Measurement August 3 at 5:00 p.m. made depression of the lake below Halemaumau rim 109 feet, heights above the lake 74 feet for the central peak (a gain of relief in a week of 14 feet), south crag 59 feet, east crag 49 feet, west crag mass 46 feet, northeast floor 23 feet, and south valley 12 feet.

The week following this survey produced subsidence at the rate of about 1 foot per day, but the total was relatively insignificant as compared with the daily range. After this there was relative stability during 1917 except for the astonishing sudden uplift of the point or promontory southeast of the central crag October 24 as described earlier (Part 2; Pl. 24c).

MAPS AND PROFILES OF HALEMAUMAU, 1918

MAP OF FEBRUARY 1, 1918 (Pl. 78 a)

The month of January 1918 had introduced a rising movement with crag elevations for the top of the lava column much higher above the Halemaumau rim than anything seen during 1917. This rise began a movement that was to lift both epimagma and pyromagma above the Halemaumau rim during February and the first week of March, producing the first definite overflows of the liquid lava across the Halemaumau lip since 1894. This is an event of physical importance in that a heavy weight of the basaltic lava column is shifted from the epimagma to the country rock of the Kilauea floor. Such unloading of the lava column supplementing internal tumefaction may be expected to permit an immediate springing up of the epimagma and the basin of the pyromagma, and this is what occurred. The map of February 1 (Pl. 78) may be considered the preparation for the map of February 28. As stated in Part 2, this crisis imposed great difficulties on the Observatory, as the pit surveys could no longer be conducted from rim monuments looking down, and these monuments anyway were partly destroyed by overflow. Sketch maps had to be made from positions on the live lava crags. The Halemaumau lava lakes were to rise above the rim of the pit, and the old features of that rim itself were to be overflowed; they cracked to become new centers of eruption, and the rim was crushed upward and outward by the epimagma column to form marginal pressure ridges.

The map of February 1 exhibits such a pressure ridge at the southwest station. The section passes through the ridge and at the southwest shows horizontal floors of overflow overlying the sector of epimagma of the southern crags. This sector was being tilted up with the hinge line of its shell against the Halemaumau wall. The result of such hinging uplift under a heavy body of hardened overflows in the wall valley is to crush the rim of the pit (Pl. 28) upward and outward into a pressure ridge. In the wall crack underneath this liquid lava was feeding these sectional corner flows, and this series of flows was supplied by repeated gushings from the ponds and cones along the wall crack farther northwest. At the opposite northeastern side of the section, the upward thrust of the epimagma had broken loose the old 1894 ledge at depth, so that a concentric ancient wall crack had there started to erupt under the northeast station, and a pool of lava was beginning to fill the wall valley on the northeast side of the 1894 ledge. This 1894 wall crack bears the same relation to Halemaumau that the Volcano House sulphur-bank crack does to Kilauea Crater, but the sulphur flat wall valley represents a prehistoric edge of a higher Kilauea floor.

While commenting on the wall crack, meaning the fissure between the inner plug and outer wall of any crater, we would call attention to the linear arcs drawn on the map from the south tunnel to the northwest cone, and from the northeast tunnel around the east side of the east island crag. These arcs are drawn around the center of the lake, which is also over the center of the epimagma. Both arcs are along lines of breakage in the epimagma, where chasms have been converted into crusted-over tunnels that convey part of the circulation of the pyromagma. On such concentric breakages of the epimagma around the central shaft below we got the sudden bench lowerings and central crag uplifts in 1917. These breaks concentric with the wall crack mark the disruptive stress applied to the crustal hardened portions of the epimagma, by its temporary lowerings within a circular funnel, that oppose with friction of inward sloping walls the free lava movement in an upright shaft somewhere beneath. Taper cakes are bounded by graben faults.

A subsidence of lakes began January 25, 1918, continued for 3 days, reached a depression of 50 feet below the rim of Halemaumau, and then changed to rising again. The rising was interrupted by pulsations of sinking, and at the end of a 9-day period following January 23 the lake level was lower, and the index crag was higher. The sinking spell destroyed a conspicuous tower on the eastern peninsula, tilted the southeast crag northward, developed a new pond south, opened the concentric chasm northward from the northwest cone, and greatly changed the north arm of the lake.

By measurement on February 1, at 5:00 p.m., the lake depression below the rim of the pit was 44 feet, and the elevations above the lake were central crag 90 feet and east ledge 61 feet. The lake was high and rising, level with the new margin of the bench and overflowing it in places. High gas pressure ballooned the crust, made many flames, and there were central fountains that broke out and migrated with the current. A fall of rock from the southeast crag produced intense fountaining so that the rising hot gas started a whirlwind which carried up flakes of the broken lava and made a noisy tornado for the greater part of a minute. The fume was very thin, and in the evening the fountaining was luminous as seen from the Observatory.

The lava lakes subsided a few feet during the week following February 1 and then recovered, and the crags on February 8 were slightly higher. The net effect was stationary condition with the liquid lava about 40 feet below Halamaumau rim.

MAP OF FEBRUARY 28, 1918 (Pl. 78 b)

This map shows Halemaumau overflowing in many places and welling up back of the 1894 benches at the northeast and west. This overflow began February 23. The record of the time shows the expectation of a possible equinoctial rising in March, after the January–February lowering, and this description follows:

Then came the pre-equinoctial rise and the spurting up of liquid lava beginning February 15, around the pit floor margins, in depressed areas, which filled quietly with large crescent-shaped outlying lakes. These are quite symmetrical lying between the three great sector crag masses and the outer wall, the sectors being lifted at the pit center, and the older lake occupying the three radial fractures between the sectors. This arrangement is a doming of the epimagma carapace, its rupture along three radial cracks, and the welling up of the liquid lava through numerous shafts. The doming or intumescence of the hard floors of overflow had been the most remarkable feature of the last year; these were lifted into crags sometimes 90 feet high, and this hard substance had risen faster than the lake so that the dish holding the lake had gone up bodily without construction by overflow. In February this movement was communicated to the edge of Halemaumau southwest, mashing up that margin of hard country rock by 10 to 20 feet as the swelling up of the central crags pinched the fresh fill of lava between them and the wall and so displaced the wall (Pl. 28c).

On February 23 the lava lake overflowed the southeast rim of Halemaumau at 5:09 a.m., covered the automobile parking space 5:41 a.m., and by 8:30 a.m. had traveled half a mile east-southeast and was slowing down. There were strong renewals of overflow about 1:00 and 6:00 p.m. The southeast rim of the pit was buried under flows, and the rising of the lake was so rapid that its rampart was built and lifted about 5 feet above the old rim of the pit, with spatter heaps 5 to 6 feet higher. The overflow lava was heavy pahoehoe with aa arborescence developed in the cracks. In the afternoon a spurting driblet cone was built up at the south station and sent flows inward into the southwest wall valley. The west niche developed driblet cones, and the northeast fill built up a large driblet dome on its eastern surface. The southwest station on the edge of Halemaumau was pushed up into a half-dome about 6 feet, so that the artificial survey platform was tilted southwestward.

There was temporary lowering with cessation of overflow February 24 followed by temporary rising about noon, 6:00 p.m., and near midnight; this tendency to a 6-hour period was noticed throughout the week. February 25 produced new floods of overflow south and southeast, and the northeast fill was arched up over intruding lava below. The crags had risen strongly, and a remarkable development of new lakes in all the wall valleys indicated prolonged lift of the epimagma so as to open a crack in the circle of the Halemaumau funnel. The northern arm became crusted over heavily, and inspection of the various source vents indicated that they were identical wells with those mapped in 1917. The west niche cone and the large flat of fresh lava around it broke up suddenly, liquid melt spouted like an artesian well, then the swollen surface of the whole field broke into slabs 2 feet thick which foundered while the liquid splashed over the edges of the swollen ponded area which stood distinctly higher than its margins. The surface quickly cooled to a flat expanse.

The new overflowed Halemaumau was now extended into a slag heap that sloped off to the southeast to new flows continuing to spread at the south. The wall valleys of the pit were filling up and overflowing east-northeast, north, and west. The great crags rose beyond all belief, so that Halemaumau had become a serrate hill, and the higher crags overtopped the southern wall of Kilauea crater as seen from Volcano House. The lava lake edges were 15 feet above the old rim of the pit. The wedge-and-lift action of Plate 28 had now heaved up the whole south to southwest rim of Halemaumau by outward mashing. Accompanying the unusual gas pressure and rapid rise of the lava were several small earth jarrings and two pronounced earthquakes.

On February 26 an open pond had formed in the wall crack at the west, and the cone south of it was a remarkable object built up 20 feet high with a sculpturing shaped like a griffon. The view of Halemaumau from the road southeast now showed only an upward slope surmounted by fire-lit mountainous crags, an occasional fling upward of glowing lava in their midst, the south cone flaring stationary like a lighthouse, while below in the foreground a pattern of red glowing flows made the whole smoking mass look as though it were perforated with fiery apertures.

The southwest rim had been pushed up 9 feet, the wall remaining vertical on the pit side but showing a half-arch profile on the outer side, the ridge being 15 feet or more wide. The movement had been on numerous fissures in the country rock parallel to the edge, the ledge moving like broken wax. The movement was gradual, but it happened within a few weeks. To one walking around what had been the pit, the former edge for several hundred feet was a steep obstruction which cut off the view, and this pressure mechanism explained the old "half-dome" on the northeast edge of Halemaumau at the northeast station (Pl. 9b), which had been pressed up in 1894.

It is difficult for geologists to conceive of the astounding rapid transformation in a few days, when the so-called "liquid" lava column in a pit unloads itself of fluent lava, and its semi-solid red-hot differentiate suddenly tumesces into a gigantic swollen pudding far above the edge of the pit (Pl. 25). This shelled-over mass of rounded elephants' backs and smoking crags had its lowest part at the southwest valley 12 feet above the old rim as a swollen slag heap. The southwest pond was an arch of crust, and the inner fill next to it was a towering crag with the southwest cone on top of it high above the rim of the pit. The west niche, a solidified cove of 1894 on top of the high west cliff of Halemaumau, had been merely a part of the edge of precipices, with a half-circle of old rampart bounding a slabby plateau. (*See* maps for February 1 and for 1917.) Even as late as February 1 one stood on the edge of a 40-foot wall and looked down at the inner landscape, with the northwest pond bubbling in the wall crack at the foot of the cliff. This pond now on February 28 had an arched crust of lava above the level of the Halemaumau margin, and trickle flows had poured out on the plateau from five cones on the surface of the pond. Some of these were hissing, trickle flows were moving north, and still farther north at the northwest station the remnant cliff was about 5 feet high. So the liquid lake was not now visible from any part of the former rim of the pit; it was everywhere uphill. There had been a pond 2 days before covering the 1894 ledge northeast. The northeast sector of crags had so lifted up at the center and tilted back as to carry up the former pond crust with it and make thereof a shore for the newer pond; trickle overflows were crossing the rim of Halemaumau there.

If one climbed uphill over crusted red-hot epimagma to look into the canyon that was now the lake, the relatively small volume of pyromagma was 3 feet below its bank, sluggish, covered with heavy crusts, and fountaining in the three coves. Motionless crust flats over the north arm suggested that the bottom epimagma had been pushed up leaving the conduits and sinkholes open to the overflow tunnels only. Over the whole of Halemaumau 10 or 12 of these wells were known. Apparently the pyromagma expending in overflows and fillings was being impoverished at its usual haunts, the lakes, and these were being replaced by the underlying paste.

Measurements on February 28, 1918, above east rim elevation 3705 feet made the lake 25 feet above the rim, the central crag 101 feet, northeast peak 93 feet, older western crag mass 50 feet, and the newer uplifted crags northwest and southwest about 66 feet above the east rim and 50 feet above the west rim of Halemaumau. The west rim at all times had been 10 or 15 feet higher than the margin usually visited by travelers at the east and south. It should be realized in studying the section of February 28 that this is on the line in plan of the lava lake and the lowest crags. It exhibits the overflow to the southeast and on the west niche. To understand the greatest relief, imagine the section of February 1 with its lowest floors 15 feet above the pit rim, and the lake 10 feet higher. The country rock outside Halemaumau (datum stations) was unquestionably swollen up, but this was not checked by levels until later in the year (*see* map of December 24, Plate 78) when 5 to 12 feet of increased elevation was found at stations that were partly new, and in some cases on ground raised by overflow layers.

The week after February 28 the Halemaumau lava column ceased overflowing, and the liquid lava subsided 40 feet, with accompanying subsidence of the crags. The lowering started suddenly in the early morning of March 3; the lake started recovery March 5 and in 3 days rose 20 feet. The crags lowered until March 6 and then became stationary. This was a time when telescope observations from the Observatory were valuable, for trigonometric data were hard to find. The recovery of the lava column passed the equinox and continued until the end of March, when a big postequinoctial subsidence set in (Pl. 75c). The maximum depression reached about April 5 was 240 feet for the lake and 108 feet for the central crag; then the lava lakes rose relatively to the crags. A low level ensued, with the usual spectacular incidents of adjustment of crags, lakes, and inner floods of lava followed by a rising in May. The rising greatly drowned the crags at first as shown by the surveys of April 26 and April 30 (Pl. 75c), but thereafter the epimagma as represented by the central crag made rapid uniform gain.

This entire episode of the winter and spring of 1918 with the lava column achieving overflow, relieving itself of gas, and maintaining internal integrity by the huge volume of epimagma and the very minor volume of pyromagma demonstrates the domination of the heavy slow-moving paste differentiate as the subject for volcanologic investigation at craters. The volume of the vitreous surface skin and the really glassy vesicular basaltic foam that played any part, other than as a spectacle of burning and discharging gases, from 1912 to the overflows of 1918 was trivial in comparison to the millions of cubic meters of differentiated paste maintained at a lower temperature apportionate to its mobility, which occupied Halemaumau pit and the shaft under it during all these years. The Observatory was thus learning that the mere lava-lake studies of the nineteenth century (its own quest in 1912–1914, Part 1) give no quantitative concept of the Hawaiian lava column. The observation of a fiery pahoehoe trickle or a spectacular channel at a flow on the mountain flank gives no conception of the volume of the important substance that emerged from the mountain. The observation of the spectacular and the dramatic are informative about the local and qualitative features, but not about the general, slow, profound, and quantitative process.

The relationship of this quantitative argument, concerning the large volume in a volcanic system of the semicrystallized hot paste and the vitreous gassy melt as a small-volume remnant of the deep magma, to volcanoes in general, and to intrusions, is far reaching. The epimagma in the cumulo-dome eruptions like Mont Pelée or Tarumai is the principal magma seen, and the glassy portion is carried away with the gases as glaze, pumice, and vitreous ash. In intrusions the gaseous and vitreous secretions of the magma are expended in volcanism higher up in the crust of the earth or are completely exhausted by crystallization of all the glass and expenditure of the vapors to mix with the water zone and ore deposits. Obsidian and pumice in Yellowstone and New Zealand become the equivalents of the pahoehoe or pyromagma of Hawaii. All pumice is fundamentally pyromagma, and if it is blown to pieces as at Sakurajima or Krakatoa (Koto, 1916a; Stehn, 1929) by sudden yielding of the edifice or by complications with ground water its presence indicates that in the invaded deep region the magma was making, in minor volume, the vitreous foam that in Hawaii it makes all the time at the surface because the high temperature and fluidity of the basaltic glass are right. The steady overpowering pressure of the epimagma, recorded by the large-volume tumefaction (Wilson, 1935) in Hawaii at its maximum near craters by the superficial crushing of the edge of Halemaumau just described at the southwest station, and by lift of a marginal hill northeast in 1894 (Hitchcock, 1911, p. 237), gives a hint of how intrusion may lift volcanic mountains and possibly also tectonic continents when magmas become refractory in their viscosity and widespread in their intrusive quality. Whether the pressures that lift Hawaiian epimagma are part of the deep rising of the hypomagma, or in some way indigenous in the relation of gas vesiculation to tubules full of pyromagma, or to the complexities of heat and crystallization, is a matter of opinion to be worked out on a quantitative basis.

If the pyromagma, becoming attenuated from below upward and replaced with a much heavier, less compressible but still mobile crystalline paste, leaves behind a connecting pressure link between the surface of the earth and the ever-rising hypomagma below, then we have to grant some power that connects eruption and underground intrusion with the inner earth; and epimagma may connect underground condensation of intrusion everywhere with isostasy, as weight (Daly, 1938, p. 24, 26, weight of plateau basalts). The formation of epimagma by loss of volatile constituents agrees with laboratory results (Adams, 1938) that such loss "causes a very sudden change of viscosity from a relatively fluid to a very rigid state." While condensation reduces volume, kinetic tubulation by gases and convection maintains magmatic pressure.

MAP OF MAY 8, 1918 (Pl. 78 c)

The outstanding features of this map and section are the greater depth of the pit, the diminution of the lava lakes, and the increasing conquest of the crags by the overflow floors. Another new feature is marginal talus from the breakdown of the walls. The revelation of the true funnel of the pit, not yet approaching a vertical shaft, prompts one to question at what depth and at what diameter the flare of the funnel changes to vertical, or a reversed funnel (Bailey, 1924, Fig. 1, p. 12).

During the week ending May 10 lava rose continuously as measured at the central crag, the lake in its inner depression remained low, and at times the epimagma rose while the pyromagma subsided. In general the central crag and the lake alternated in pulsations of rising. From May 5 to 10, the crag rose 8 feet in 5 days averaging 1.6 feet per day, while the lake rose 9 feet averaging 1.8 feet per day. From May 6 to 8, the lake was sinking while the crag was rising, the liquid tending to surge up and down in strong pulsations while the stiff crag made slower spurts. The sequence was:

May 5 to 6	crag up 2 feet,	lake up 7 feet
May 6 to 7	crag up 1 foot,	lake down 7 feet
May 7 to 8	crag up 4 feet,	lake down 1 foot
May 8 to 10	crag up 1 foot,	lake up 10 feet

In the forenoon of May 8 the main lake was 167 feet below the east rim of Halemaumau, summit central crag 78 feet, north smoke crag 126 feet, west crag 115 feet, cone over west source pond 144 feet, and southeast pond 175 feet below the rim.

As usual the west and southwest ponds, the former surmounted by a cone, were higher than the main lake, streaming was eastward, and the southeast pond was lowest of all, undoubtedly a sinkhole. The elevations above sea level were west pond cone 3561 feet, southwest pond 3543 feet, main lake 3538 feet, southeast pond 3530 feet. As usual the wall valley was the lowest part of the floor, and this was occupied by another sinkhole pond at the north, with evidence of a tunnel under a line of cones and pots from the western end of the lake northeastward. A similar line but marked by cracks extended from the southeast corner of the pit to one of these glow pots, and a third line of cracks extended across the southern side of the pit, making with the other two a somewhat equilateral triangle, with overflow cones at the corners. Possibly this triangle of straight breakage around the central crag and the lake outlined three cracks across the three sectors of February. These cracks were parts of the structural breakdown of the concentric domical chasms and tunnels exhibited in the map of February 1.

Most of the features of February 1 could still be traced in the lowered and crushed epimagmatic crust with the crags preserving much of their integrity. This was particularly true of the northeast group of crags which now presented the same steep escarpment facing inward and a curious rounded backslope crowded against the northeast wall of the pit. There was a notable hollow between the two remaining northeast ledges, and the recovery of April had caused the main lake to overflow into it. The north arm of the lake was preserved by the tunnel, cones, and pots, the southwest cove had become separated off as a pond, and the southeast cove was buried within a tunnel, a cone, and a pond. All this was within smaller compass by reason of being crowded downward and inward by lowering. As shown in the section, tunnels at the northeast and the south, submerged under crusts and a pressure ridge, contained live lava.

In the week following the time of this map lakes, crags, and floors rose about 20 feet, with continued alternations between the gushing up of the liquid lava and the slower lift of the epimagma. The swelling up of the latter produced deep crevasses in the overflow floors. There had been some uplift of the central lake area so that the north shore stood 15 feet above the liquid while the bank around the east end was only 5 feet high. This was adjusted before May 18 by lift of the eastern shore line so that the inner cliff all round the lake was once more of uniform height.

MAP OF DECEMBER 24, 1918 (Pl. 78 d)

The interval between May and December has been described in Part 2. The rising spells of the summer and autumn were interrupted by the northern outflows of November, which lowered the lava column the last half of November like the February-March high level with overflow outside of Halemaumau. The general seasonal curves of pre-equinoctial rising, postequinoctial sinking, presolstitial rising, postsolstitial sinking, rising to autumn equinox, sinking in October, and recovery to December solstice were somewhat alike in 1918 and 1917 (Pl. 75b, c). In 1918 all levels were higher, the movements were more intense, and the marked difference was the two subsidences that followed the overflows; 1917 had no overflows. The relief of the crags above the liquid lava became very conspicuous in the early part of the last half of 1918, but after the great November lowering the liquid lava gained on the crags more than ever before, and the map of December 24 shows the remnant central crags almost completely buried under overflow floors. There were still pool sources, cone sources, slag heaps, and pond cracks representative of heavily crusted lakes beneath, and one open lake remained—an oval pond only 130 feet long preserving the eastern pool of the May lake. For the rest the rising pyromagma was so dominant in the weeks preceding 1919, destined to be a year of continuous outflow high level, that there was very little sinkhole action; apparently some of the sinkholes of the convection had reversed themselves to become source wells. Sinkholes and tunnels were concealed under the floor, so that the liquid lava welled up the eastern wall cracks, and the flow pattern on the surface of the nearly flat floor showed just as much unusual streaming from east to west as in any other direction. Repeatedly there had been inpouring of lava flows from floors into the cup of the lake. The section shows how marginal slag heaps had been built up where crags had been—at the south, northeast, and west of the center. Undoubtedly these crags still existed, buried under the floods of slag. Feeding source wells for the ponds on top of these slag heaps had grown upward as accretion centers. This time of domination of pyromagma sources was the time of the great tilt away from the Kilauea center (Part 3, Pl. 87).

MAPS AND PROFILES OF HALEMAUMAU, 1919

MAP OF JULY 10, 1919 (Pl. 79 a)

The year 1919 represented the culmination of the phase of 1917–1919 that led to the third Mauna Loa outbreak of September-October 1919 (Pl. 74). The details of 1919 are described sufficiently in Part 2, which indicates how this year in its first 2 months repeated the lift of the lava column to move outflow from Halemaumau to the Kilauea floor. The liquid lava in flooding the floor of Halemaumau from several slag heaps submerged the last peak of the central crag and left nothing of that particular peak to measure as a much-used index of height of epimagma. During 1919 the epimagma floor reasserted itself by a lift in the center, a split into three sectors, the development of three lakes in plan like a clover leaf, and the maintenance for 10 months of high level with outflow represented by the map and section (Pl. 79) of July 10, 1919. This map may be considered a type for the whole year until the end of November, except that the pattern of the lakes varied a little. There were no elevated crags, but there were gradually lifted escarpments of the floor, becoming plateau sectors bounding the lakes. Overflow from wall pools and border cones, or outflow from outlying cracks of the Postal Rift system, across the floor of Kilauea Crater, was continuous most of the year. The spasmodic overflows of 1918 followed by deep subsidence were replaced by steady overflow in 1919 and only slight subsidences. Hence the steady tumefaction of Plate 87. Halemaumau pit was nearly obliterated and filled by a low dome with lakes in its tripartite radial fractures. This is comparable to the dome period of Halemaumau 1849–1852 (Dana, 1891, p. 80–81).

There were new pressure ridges where the epimagma was locked to the pit rim. The flows from outlying encircling cracks of Halemaumau were from greatly tumefied parts of the Kilauea floor, and rivers of pahoehoe became crusted over and flowed in tunnels for miles to and along the base of the encircling cliffs of Kilauea.

The map of July 10 followed a moderate subsidence of the June solstice, with the lakes lowered in their cups and the rim wall of Halemaumau temporarily asserting itself. The week preceding had shown much slower but continued subsidence and some recovery of the liquid lakes, the levels of which stood 28 to 40 feet below the inner cliffs of epimagma surrounding them. A comparison with the map of December 24, 1918 (Pl. 78d), shows that the three lakes occupied the sites of the former west cone, north cone, and east lake. As usual the southwestern lake was 10 to 12 feet higher than the other two and was the source well; the others stood over sinkholes. At the source opening of the recent Postal Rift (Pl. 9b, c) flow, north of the area of this map, there had been much collapsing, revealing hot caverns and a well, now all dark.

The main or east lake on July 10 had risen, showing marginal fountains under shells along the side cliffs and having a slight westward streaming. The northeast wall pond was smoky, the north lake was quiet, the western lakes were very quiet, and heavy fume rose from the west pond. The southwest wall pool was enlarged and very hot. The central pond was nearly hidden by an overhanging shelf of lava crust. The east wall of Halemaumau was 35 feet high with a live rumbling chimney in the cone beneath .The north lake was lowered in its basin and was streaming away from the east bank toward a new curtained grotto on the northwest side.

The new crack at the northwest station on the outer rim of Halemaumau extended outside the limits of this map through two sulphur patches to the Postal Rift source cone. The fault block on the Halemaumau side of this crack had sunk about 3 feet. Other cracks back of the northwest station made a tumbled crevasse 10 feet wide, which extended narrowing toward the south. The west pond was crusted over, stood about 40 feet below the west station, and had two small pots showing lquid lava 4 feet down. The southwest lake was fountaining in its western cove and showed westward streaming. The flat south of it was a continuous plateau and the southeast wall pool was a deep smoky chasm where invisible lava could be heard rumbling far below. The south arm of the main lake showed a circular pool of glowing lava in heavy crust, and the latter covered with a mat of Pele's hair. The highest actual wall of Halemaumau proper was at the northwest, but the highest topographic features of the pit rim were the slag heap remnant northeast and the pressure ridges southeast and southwest. Halemaumau had become half cup and half dome, with crusted and swollen floor dominant.

The map shows the conditions that obtained all through the experimental measurement of lava-tide movement at the North Lake of July-August 1919. The tent that sheltered the transit had to be moved August 4 from the northeast to the north position owing to built-up rampart obscuring view of the north lake. The two positions of the transit are shown, the lines drawn indicating the points measured for vertical angles, with reference to the level bubble; two of these points were shore locations at the fountaining margin of the lake (changed as shown), one was a bench mark on the epimagma of the northeast sector (elevation 3719 feet), and one was the relatively fixed monument of the west station to be used as a datum point for the rising of all the inner stations (elevation 3728 feet). The transit tent itself rose on top of the stiff lava column during the month of observation. Weekly surveys from outside Kilauea Crater were made to check the change of elevation of the west station, and daily surveys from rim monuments checked position of inner stations (Jaggar, Finch, and Emerson, 1924; Brown, 1925).

The week following July 10 slight rising occurred, which was communicated to the shell of epimagma, the main effect for the liquid being at the west as usual. The lakes were notably quiet, dull, and crusted. In a week the southern epimagma cliffs rose 1–2 feet, while the northern ones lowered by similar amounts. The west pond rose 8 feet, the southwest and east lakes 2 feet, and the north lake lowered 1 foot. Such was the general situation in July, but for the month following July 19, when the lava-tide survey began, there was strong rising, with overflows, and once more the northwestern Postal Rift burst into outflow that poured westward to the foot of Uwekahuna bluff.

The July map exhibits the appearance of Halemaumau until November. The

Postal Rift flow continued, and when the Alika flow started from Mauna Loa at the end of September the activity of the Postal Rift flow of Kilauea increased. With the gradual cessation of Mauna Loa activity early in November, Kilauea again increased its overflows, and about November 21 the gas pressure under Kilauea was so high that even the lava lakes of Halemaumau overflowed, along with the outflow of the Postal vent.

Apparently the yielding of Mauna Loa released underground pressure to induce frothing in both volcanoes, but the sealing up of the Mauna Loa rift temporarily put added pressure of effervescence on the Kilauea vent. This was short-lived, however, and the breakage of the northwestern Halemaumau rim rock, back to the Postal Rift, had prepared the pit for great enlargement in that direction, when subsidence by the yielding of Kilauea set in. The "yielding" really means an elongated deep wedge splitting of the crateral rift through the whole mountain with dike intrusion temporarily replacing crateral extrusion. (*See* summary of December Crisis, hereafter.)

A comparison of the maps of November 28, December 9, and December 15, 1919 (Pl. 79), with the November subsidence of Halemaumau shown in Plate 75d exhibits the most quiet, rapid, and profound downplunge, followed by immediate recovery, that the Observatory has ever measured. It was prophetic of the succession of drops during the next 5 years (Pls. 74, 44c, 45a).

This extraordinary crisis and its sequences are described in Part 2 beginning with the pit-bottom subsidence and ending with the start of the Kau Desert flow. Thus the entire lava column went down approximately 600 feet in a few hours, revealing a vertically striated ring-dike for more than 500 feet. The strain broke open a northeast-southwest crack in Kilauea floor athwart the center of Halemaumau, revealed in both walls of the pit as a chasm, gaping open downward; 3 weeks later a spectacular rising of the lava lifted with it a column of epimagma with a crest shaped like a calyx or shallow wine glass. The upward pressure of the recovery opened the new crack clear through Kilauea mountain by the wedging action of the rising lava, so that in December outflow ensued in the Kau Desert to the southwest (Pl. 85, map).

MAP OF NOVEMBER 28, 1919 (Pl. 79 b)

A reaction of subsidence had been expected after the gas and lava release of the combined Mauna Loa and Kilauea outflows. On November 28, 1919, a quiet drop of the Kilauea lava column about 2:00 a.m. accompanied by pronounced earthquakes reproduced on a much greater scale the lowering of June 5, 1916, which also had followed a Mauna Loa eruption. Within an hour after the disturbance started, the whole ancient pit of Halemaumau was revealed to a depth of 400 feet (Pl. 79b), the topography of lakes and escarpments was largely buried under encircling talus, and a single new lake of liquid lava had started to reform in the middle of the cup. The Postal Rift flow continued its outpouring onto the Kilauea floor through its source well up to the moment of crisis, when it instantly ceased to flow, and the tunnels were left glowing and void. There resulted in the great pooled flow of the northern part of Kilauea crater reactions of collapse and fountaining, owing to the withdrawal of adjusted gas and lava pressure. The liquid lava in the bottom of Halemaumau recovered very rapidly and by November 29, in 1 day, was already forming a large lake.

More than 200 shocks were instrumentally registered during the subsidence. At 2:05 a.m., November 28, the profile of dome, lava lakes, and cliffs of the inner sectors of epimagma, as seen from the Observatory, flattened out and disappeared beneath the edge of Halemaumau in less than a minute, and there was left the glowing cauldron with dense avalanche clouds of dust, while a continuous roaring was heard from the many slides started by the earthquakes.

Inspection thereafter from the rim of the pit revealed sliding, the walls nearly vertical; big talus cones with glowing edges could be seen far below, and a small partly crusted lava lake was bubbling along its edges and spurting brightly through a crust crack in the middle. Heavy avalanches were rare. No falls were seen of the actual upper edge, though this was cracked and overhanging in places. On the rock wall inside, a layer of cracked glowing matter (*see* "veneer" on map) formed a lining which frequently scaled off on the surface in powdery avalanches of glowing matter. There was some puffing from vents in the bottom. The upper circle of the pit was extended northward by collapse of all the cracked region north-northwest. The lowered edge there made irregular terraces down, for perhaps 100 feet, to where the old pit margin below was defined as a cliff.

At 10:30 a.m. the lava column was adjusted, a small triangular lake lay 591 feet below the northeast station, and the floor consisted of large surfaces of cracked epimagma lowered bodily with the dome of the previous day. There were traces of the clover-leaf topography, and the remnant pool appeared to be the north lake.

The lake was crusted with occasional cracking and foundering of the skin, two or three sluggish fountains broke loose, and driblet cascades poured into the lake from a fissure heap at the west. Farther west there was a puffing cone, where trickle flows had poured across an old bench magma surface coated with Pele's hair.

For the whole Hawaiian system, this instantaneous subsidence in Halemaumau after a whole year of Kilauea high level, and culminating a sequence of summit outbreak and flank flowing on Mauna Loa, demonstrates sympathy of action between the two volcanoes and proves they are connected by underground conduits. It can be seen from the record for 1914–1916 (Jaggar, 1917a, Mauna Loa, 1920, p. 173; Pls. 74, 75a) that the events of the successive Mauna Loa-Kilauea activities of 1914, 1916, and 1919 were in similar sequences, with increase of interval, increased volume of outflow, and for Halemaumau increased height of vents, increased speed and depth of the subsidence reaction, increased rapidity of the recovery, and decreased intensity of the seismic crises as though the Kilauea edifice were becoming lubricated.

The week preceding this astonishing subsidence of November 28 had maintained the dome of crusted epimagma at Halemaumau high above the pit rim, so that the Kilauea lava lakes were in elevated cups, with fountains and escarpments in full view from the Volcano House. Hundreds of visitors had climbed on top of the inner cliff to view the lava lakes from above and had stood upon the lava column that subsided so quietly and so suddenly. Through July-August the Observatory staff was encamped on this same lava column. It is disturbing to think what might have happened had the subsidence taken place then or in daytime.

The only event during the week preceding the subsidence that suggested crisis (*see* Plate 79a) was that the south arm sinkhole pond on November 23 sank 10 feet lower than the main lake, so that through the connecting channel a cascade was falling continuously with a roar, converting the pond into a whirlpool. From a distance at night, Halemaumau was unusually bright owing to brilliancy of the cascade locality, and the Postal Rift outflow was also very brilliant. After midnight the south arm rose and stopped the visible cascading which was replaced by grotto fountaining, but the convectional current continued. The Postal Rift flow, and subsidiary outwellings of lava near its source cone, showed no relaxation of outflow, so that the new covering of lava in the northern part of Kilauea Crater, together with the fresh outflows from Halemaumau on other sides, made an area of new lava occupying nearly a quarter of the greater crater. New fingering flows were making out along the base of Byron's Ledge at the northeast margin of the Kilauea floor, and the large fields of new pahoehoe lava had covered the western, northern, and northeastern parts of the crater along the wall valley.

Two hours before the crisis there was nothing new about the condition of Halemaumau. The main lake was 6 to 8 feet below its banks, and the Postal Rift source cone was pouring out its torrent through tunnels to feed a very bright northern flow area, 2 to 5 miles away within Kilauea Crater, following the course of the tunnels and puddling and spreading as usual.

At 1:42 a.m., November 28, earthquakes were registered on the seismographs; about 2:00 a.m., 5 or 6 pronounced quakes were felt, and then came 75 felt shocks within 2 hours. The great brilliancy of the south arm pond region at once indicated that the flaming cascade had been renewed, and this light sharply outlined the crag profile (Pls. 31a, c, 34b), 40 feet high on the southeast side of the north lake. In less than a minute this cliff flattened out and disappeared, then the entire Halemaumau inner dome went out of sight, the five openings of the Postal Rift tunnel lost brilliancy and became dull as the flow ceased within them, and within a few minutes dense avalanche clouds of dust went up from the pit with a continuous roar. The earthquake swarming ceased after daylight, indicating rising. The measured subsidence was 591 feet at 12 noon, November 28; rim station above sea level 3727 feet, liquid lake 3136 feet.

The week following this crisis was introduced by measurements of December 2 that showed a ring of old bench at first lifted more than the lava lake. This rise was 33 feet in excess of the rise of the lakes, and the lake lava had risen 145 feet in 4 days, making the average upflow of 36¼ feet per day. The liquid lava in wall-crack ponds stood 50 or 60 feet higher than the central lake, so that their rate of rising had been 50 feet per day. The lava column as a whole thus rose 200 feet in 4 days, this including the lake, its confining basin of epimagma, and the liquid welling up the wall crack.

The upper rim of the pit was now oval with a diameter of 1200 feet east-west and 1485 feet north-south. The lowest terrace of the new northern inner shelf stood

85 feet below the rim. The ring of talus, epimagma, and pyromagma was something over 1100 feet in diameter. The week to December 5, with its unheard-of rapidity of uplift of both foaming pyromagma around the edges and rising circle of epimagma inside, proceeded as follows:

The liquid lava on the first day increased to a large lake; on the second day cascades were pouring into the lake from springs of lava which welled up behind the talus. Incredible as it sounds, the ring of epimagma under the border talus rose bodily and tipped toward the center, the talus cemented with lava parting from the walls and becoming an annular crag. The gaping wall crack so formed engulfed parts of the talus, and finally by the end of the week long curved crescent ponds of boiling lava developed in the encircling crack, rose 100 feet or more above the quiet central lake in the saucer, and then cascaded inward over the ring crags so as to increase the volume and height of the quieter inner lake.

The pre-subsidence topography was more completely preserved than had been apparent under the high talus cones made by avalanches. The arched surface encircling the three lakes became a basin surface enclosing a single lake. The angle of slope inward appears to have been increased as the deepening lake became heavier and the semisolid matter beneath was squeezed outward and upward to the wall crack. This was a reversal of the process so often seen in earlier years, when the wall-valley fill weighted down the margins and pushed up the center.

A new feature created by the deep crack in the Kilauea floor, straight across Halemaumau, was a smoke hole outside Halemaumau on this vertical fissure 300–500 feet southwest from the pit and trending radially away from Halemaumau toward the Kau Desert. The rising smoke was dense blue and sulphurous along 200 feet of the line of fracture, the rock of the 1919 flows adjacent to it was stained, and the crack was very hot. Its opening was about 6 inches wide, and it smoked sulphurously more densely than any other vent. The trace of this crack, vertically down the inside wall of Halemaumau southwest, was wider at the bottom, and across the pit its extension could be seen in the opposite wall, but it emitted no smoke there.

The Postal Rift flow was caved in at its source openings and at several places along the tunnel for half a mile to the northwest. Near the source the interior spaces were dark; farther away along the tunnel stream bed there was red heat revealed through windows of collapse; but the fifth opening of the tunnel showed the interior brilliantly yellow with incandescence along a subway 26 feet high, with breatheable hot air emerging from the window at the top. There was still fountaining in the lava flows, along the northeast edge of the Kilauea floor (Pl. 84b, map), indicating continued flow and gas-bubble emissions in the tunnel system, which had more than 150 feet of vertical hydrostatic head in 4 miles from source to front.

MAP OF DECEMBER 9, 1919 (Pl. 79 c)

The liquid lava by December 9 had risen 330 feet, and the northern crag peak of the annular ridge stood 123 feet higher (Pl. 75d). Already in 11 days the vast pit of November 28 was half full. The history of the week following December 5 showed that rising proceeded by alternations of spurts between pyromagma and epimagma. For 2 days after November 28 the lake basin filled rapidly, for the next 3 days the heavy ring crag became defined, then the liquid for 2 days boiled up wall cracks and cascaded inward to fill the basin, but in the next 3 days an uplifting movement developed the great circular craggy ridge until its summit was over 100 feet above the liquid level. From December 9 to 12, a most extraordinary upwelling of violently boiling liquid flooded the pit from wall to wall and half drowned the crag ridge, so as to convert it into an island resembling a coral atoll as shown in the map of December 15.

Measurements of December 9 from the level of northeast station made the outside diameter of the ring pool about 1025 feet, of the central floor 760 feet, and the width of the marginal annular pool east and north 70 to 100 feet. The southeast wall-crack fountain only 200 feet down was evidently a source, for the northern and eastern surfaces of the wall pool were 75 feet lower, as was the crusted central lake. The narrow western spurting wall-crack fills also stood higher than the lakes.

In general, in such cases, for the same effervescent lava fluid rising from below, the narrower the crack, the higher it will rise. In other words, for a foam, the more gas that escapes the lower stands the surface.

The central lake area for a fortnight following the great collapse of November 28 rose 444 feet, averaging 31.7 feet per day, but in the last 3 days, with thousands of fountains and intense radiation of heat, the lift of the lava column was 40 feet per day, in the upper and larger part of the Halemaumau funnel. Though the container enlarged, the entering volume increased in more rapid ratio. This boiling flood was much greater in volume than anything heretofore recorded by the Observatory at Kilauea.

The multiple fountaining was like that of the spurts of December 1911 and July 1912. This analogy led to the printed prediction (Bulletin, December 1919, p. 180) that as "1912 was as a whole a year of declining lava level, the present spasm will be short-lived, and marks the beginning of a period of subsidence for the next two years." This was correct; subsidence proceeded in spasms for the next 4 years.

The bubble fountaining on December 9 was violent in the north pool as well as at the east, and at places of continuous bombardment grottoes were formed, and rampart benches were built up with crescent-shaped niches. Two pronounced capes had been built between such niches at the east. The west wall crack contained sputtering cones in a ravine.

The central lake was a raised floor surrounded by the crescent of crags lowest at the west, and this floor was now higher than the outside annular lake. The live part of the floor was a field of overlapping pahoehoe flows fed by a sluggish fountain which broke the crust occasionally, while at the north a cone belched noisily making a patter of falling fragments.

The currents of the ring-lake moved east and west from a bridge of skin at the north, while other currents at the east met, with great turbulence, making hundreds of bubble fountains and some traveling fountains.

The radial fume crack outside Halemaumau southwest had become excessively hot, with smoke thin and blue instead of the dense masses of vapor seen the previous week. No glow could yet be detected in this crack, but it developed incandescence and tumescent opening on December 14. The Postal Rift flow continued to show glowing cracks in its frontal fields, and glow continued in the intermediate portions of its tunnel. It was thought that this maintenance of high incandescence for weeks in the glaze of the interior of the tunnel might be assisted and maintained by some catalytic action or reoxidation of the iron compounds with which these glazes are coated.

The profile sections of Plate 79b and c, November 28 and December 9, are in true proportion. The representation is of course only approximate, and no attempt is made to construct in section the deeper lava column. These sections reveal how trivial in volume is the liquid lava, in spite of the brave showing that is increasingly made in plan. The stem of the main lava column of epimagma must become vertical-sided somewhere below, and in this particular rising it seemed unavoidable in drafting the section to include within the epimagma some of the sunken bench material at the north. There was no question but that great quantities of talus material of November 28 were involved in the epimagma sections of December 9 and December 15. No melting energy is present in the undercooled liquid lava.

When we remember that the new crack outside at the northwest shown in the map of July 10 was part of concentric extension of such cracks that were eruptive north of Halemaumau all through the Postal Rift flow period, and that these cracks were therefore filled with dikes down below, it is reasonable to conclude that the northern inner epimagma peak of December 9 involved portions of the downsunken benches.

This by no means signifies, however, that the main epimagma column in the depths consists of debris. It is a partly crystalline paste, incandescent and of low gas content, residual from the loss of volatiles of the glassy pyromagma, which has changed viscosity in the process of two-phase convection (Daly, 1911, p. 76).

MAP OF DECEMBER 15, 1919 (Pl. 79 d)

We now come to the first of two culminations of this very rapid rise, destined to split open Kilauea mountain in the Kau Desert southwest of the crater, for the first time since 1868. Plate 79d illustrates both December 15 and 19. The culmination of December 15 thrust the crag peak far above the rim of Halemaumau, with the wall-crack lake so close to overflow that the outlying smoke crack southwest actually achieved outflow on the Kilauea floor. This rupture extended beyond the southwest marginal cliff of Kilauea Crater and so fractured the mountain with lava intrusion far down in that direction as to lower the lava in the pit 150 feet in a day and prepare the southwest rift for the coming outflow in the desert. This lowering (Pl. 75d) is indicated in the survey of December 16, followed by very rapid recovery December 22 with the pyromagma dominant. Then began the systematic lowering of both liquid lava and crag lava, with the gradual development in January 1920 of the Kau Desert flow. The rise of December 16–22 was occasioned by a temporary resistance of the mountain to intrusion, after first rupture released vesicular expansion.

It will be seen, as follows, that this crisis actually revealed intrusion to geological inspection:

(1) The subsidence of November 28, index of the Mauna Loa-Kilauea culmination.

(2) The rise of November 29–December 15, effervescent recovery of the entire lava column under Kilauea mountain as a pulsation following the pressure release of November 28.

(3) Outbreak on the Kilauea floor and intrusion into Kilauea mountain, drawing down the Hale-

maumau column, but thereby making viscous the portion drained and again unloading Halemaumau for recovery.

(4) Temporary recovery to December 22, renewed pressure partly hydrostatic on the southwest rift, and its progressive rupture in the desert.

(5) Outbreak of prolonged Kilauea flank eruption and co-ordinate lowering of Halemaumau.

During the week of this map (December 15) Halemaumau continued swift rising almost to the lip, and on both December 15 and on December 19 sudden outbreaks of foamy thin-shelled pahoehoe flows gushed through a long radial crack on the floor of Kilauea Crater southwest beyond the smoke hole. The first outflow occasioned sudden subsidence in the pit, followed by a swarm of earthquakes with origins 9 or more linear miles (including depth) from the Observatory. The seismic activity was occasioned by the underground lava splitting open visibly a continuation of this rift outside of Kilauea Crater in the Kau Desert, where new vapor arose and new chasms yawned open profoundly.

The activity in Halemaumau continued to be stormy fountaining in a lake which filled the pit from side to side, within which the ring-shaped island slowly became more submerged. The strong fountaining was still confined to the outer annular channel which widened as the liquid rose in the funnel-shaped pit and gained volume at the expense of the island.

The highest level for the lava column as a whole was reached December 15, when the lake at times was only 20 feet below the rim, and then ensued fluctuations owing to outflow that carried the lake to 148 feet below the rim. The crag peak had been 50 feet above the rim and lowered to 71 feet below the rim, all in 1 day. The surveys showed December 12–15 that lake and crag rose about 40 feet per day; but, with the outflow and subsidence beginning 11:00 a.m., December 15, the lake sank 113 feet and the crag 121 feet in 1 day. The recovery for 3 days December 16–19 lifted the lake level 98 feet and the crag only half as much; another outflow on the Kilauea floor resulted.

On December 15 the whole crag could be seen from the distant Observatory, the fountains boiled tumultuously only 20 feet down, and the rising and the roaring implied a frothing up of gas and lava analogous to a Mauna Loa eruption. The island lay like an atoll in the pit, enclosing a quiet lagoon open to the west, in which occasionally enormous dome fountains broke the surface crust. Ramparts of spatter lumps were built high against the island, much of the ring-crag was entirely coated with such spatter accumulations, and the heat at the Halemaumau rim was insupportable without a mask. The detail of this period should be read in the Bulletin of the Hawaiian Volcano Observatory.

For several days the outside smoke crack southwest of Halemaumau had been growing incandescent. On this forenoon a bulged puddle of incandescent crusted lava 50 feet in diameter had welled up the crack about 600 feet from Halemaumau. The ground was swelling and groaning, fragments were falling in the crevasses, and small quakes could be felt underfoot and shook down loose rocks from the south pressure ridge at the edge of the pit. The noisy intumescence indicated that a lava flow was coming. At 11:25 a.m. a puff of dust and fume shot up on the floor near the southwest edge of Kilauea Crater, where in the enclosing cliff the 1868 fissures show as vertical cracks. Instantly and quietly half a mile of ground opened, and some

200 small fountains of very liquid lava burst out along the cracks, blood-red in the sunlight but becoming coated black with wrinkled skins as it spread with bubbling right and left. The line of fountains ended downhill from the smoke hole (Halemaumau pit is at the top of a Kilauea floor dome), so that an observer near Halemaumau could look into the crack and see the molten lava flowing some 15 feet below the surface. The line of the crack was radial from Halemaumau, and the 1868 cracks in the distant cliff now began to show motion with some rocks falling. There was a wide band of high safe ground on the Halemaumau rim where one could stand, looking downhill at the flow between Halemaumau and the Kilauea wall. The flood spread out along the wall base until it was a mile wide.

The liquid lake in Halemaumau was feeding this flow through the upright crack in the southwest wall of the pit open below, but with walls tight together at the upper rim. Within an hour the lake inside had drained down below the flow level outside, and the flow stopped, showing hydrostatic connection. The lake went lower, and the flow became a sheet of collapsed shells, with drainage down the source crack. After 2:00 p.m. that afternoon a swarm of earthquakes indicated that intrusion was draining the lake and splitting the mountain.

From the moment of the flow outbreak both lake and crag mass in Halemaumau went down steadily and slowly, and a marginal black ledge was left plastered as a bench 2 to 3 feet wide against the wall of the pit all around. That there was spasmodic drainage occasioning the subsidence was recorded by horizontal shore corrugations in the face of this bench, the upper ones increasing their spacing from 1 to 4 feet as the downward movement proceeded.

The rate of downward movement steadily decreased, with lowering in:

	Feet
10 minutes	5
45 "	25
245 "	90
425 "	105
15 hours more	10

Meanwhile during the day the cracks of 1868 extending southwest outside the edge of Kilauea Crater had been opening in a zone 1.5 miles long and 0.25 mile wide. The larger chasms had yawned open, engulfed their dirt fills, and some creaking and tumbling could be heard within them. The largest at 6:00 p.m. had opened 5 feet, was 80 feet deep, and this led down to a narrower space going to black depths. Vapor arose that was steamy, with sulphurous smell and a temperature exceeding 100°F. Five conspicuous steam vents were aligned across the desert. There were smaller fractures of all sizes down to minute breakages of the soil. Steam was first seen here on this day, but probably the chasms had opened slowly for several days, from the smoke-hole crack near Halemaumau outward, and deep down.

The activity of Halemaumau did not change its character. On December 16 the liquid encroached on the southern half of the island, after the epimagma had sunk faster than the liquid. The trace of the southwest rift crack, up the inner wall of Halemaumau, was standing open as a vertical chasm, after the lake had receded to a depression of 148 feet, and this chasm cut through the fresh black ledge veneer and was about a foot wide. This implied its maintenance as an opening crack under the lake, presumably full of liquid lava in the outer country up to the lake level. The recent north shelf of Halemaumau was revealed again, covered with rough black aa lava (Pl. 34d), indicating that the highly stirred bottom paste, if revealed suddenly as floor of the lake, would prove to be epimagmatic aa, or semicrystalline, as shown in February 1917 (Part 2).

Rising set in during the evening of December 16; in 24 hours the lava came up 60 feet, the streaming and fountaining was even more tumultuous than before in the ring-lake, and in the inner lagoon large periodic dome fountains broke the skin every 1 or 2 minutes.

During all this period of activity there had been occasional avalanches from the walls, the noise of the roaring fountains could be heard 3 miles away, there was more or less fuming from the crag and wall margins, and the tremendous volume of hot gas rising from Halemaumau produced convectional high-rain cumulus, with a brown fringe beneath, a thin veil of transparent bluish gas over the pit, and in the chill of evening a bank of fog would pour down over the high west bluff of Kilauea Crater like a waterfall. This marked the indraft of cooler air around the margins of the hot uprush at the pit.

It should be recorded here, without suggesting any connection, that at 7:40 p.m. December 17 an extraordinary streak of light, an explosion, and a concussion were perceived over all the eastern part of the island Hawaii, reported also from the sea at the north. The streak was from northeast to southwest and was interpreted as being a detonating meteorite or bolide passing over the island. It made no seismic record.

On December 18 the Halemaumau lava island was more submerged, the central lagoon had increased in size at the expense of submerging the southern half of the epimagma crescent, the lake was about 70 feet below the rim of Halemaumau, and thousands of points of ebullition moved with centripetal streaming in the ring-channel, out from dark skins at the wall borders.

The southwest smoke outside the pit exhibited a zone about 60 feet wide of cracks with sulphur staining, and the solfatara was smoking moderately. The extension of the crack along the Kilauea floor was 1–2 feet wide, yielded very hot air, and was lined with brownish stalactite lava or showed bubbles of lava over small vents below. With continued rising in Halemaumau this started flowing again, spreading along the base of the Kilauea wall for $\frac{3}{4}$ mile, with its source a large geyser of lava (*compare* Plate 40c) 7 feet high and three or four spurting cones along the crack.

SUMMARY OF DECEMBER CRISIS, 1919

The map of December 15 shows Halemaumau in its glory for the remarkable period from December 12 to December 23. Something like this must have happened in 1823 (Stone, 1926a; Stearns, 1926, Pl. 42) and 1868. Then also the Kau Desert rift was ruptured; the outflows poured forth, and Halemaumau was drained. We know nothing of Mauna Loa about 1823, for the missionaries had just arrived and Mauna Loa was inaccessible. That the two rifts through Kilauea and Mauna Loa, in their parallelism, are dynamically connected was shown in 1868 and 1919.

On March 27, 1868, Mauna Loa started lava eruption high up, initiating flank outflow to follow the prolonged summit-crater eruption of 1865. On April 2 a great earthquake ruptured both mountains and started complete drainage of Kilauea with an exceptional gush of lava flow in Kilauea Iki as preliminary; a trivial lava puddle from Kilauea appeared in the Kau Desert, but on April 6 there started on the southwest Mauna Loa rift low down an intense lava eruption of great liquidity that reached the sea and lasted only 5 days. The sequence was high-level Kilauea, high-level Mauna Loa, drainage Kilauea, drainage Mauna Loa.

In 1919 the sequence was high-level Kilauea, a preliminary high-level Mauna Loa gush, outflow Mauna Loa, increased Kilauea crateral floods, cessation Mauna Loa, Kilauea downplunge and recovery, earthquakes, and Kilauea drainage to Kau Desert flow. Thus 1868 and 1919 showed sympathy of the two southwest rifts, with the seismic events differently distributed, but both were times of intense pressure on the entire volcanic system, underground yieldings, and drainages. The reason for the big earthquake of 1868 was doubtless the low-level splitting stress that ruptured the southwest Mauna Loa rift after long-congealed sealing. The Kilauea events demonstrated that intrusive drainage can produce sudden crateral lowering quite as effectively as extrusive.

The vertical fracture widening downward November 28 invites discussion. We think of tension cracks as widening upward. The crack athwart the middle of Halemaumau and Kilauea sinks is the fault belt that trends northeast to eruptive fissures both ways. To the southeast are downthrown normal-fault step blocks to the ocean. Gaping downward might be due to a pivotal motion of step blocks seaward, or it might be due to the wedging action upward of stiff magma, on the deep rift as a dike fissure.

The actual observation of intrusion opening the mountain tensionally December 15–16, with instant lowering in Halemaumau, makes dike wedging the choice. Further opening, outflow and lowering after December 22, with visible splitting of the mountain and outflow for 9 miles, leaves no doubt.

The sequence of November 28 proves that the sudden lowering of Halemaumau lava was due to the same upward pressure that had been observed increasing. This ruptured open lengthwise and far down a deep dike that drained the pit temporarily. An upright chasm under Kau Desert, gaping downward, became filled with the liquid, while the weight of the mountain held the surface together. Removal of the load of the Halemaumau column released enormous frothing. When the Halemaumau load was restored on the hydraulic press, the mountain split gradually in the Kau Desert. This in January reached equilibrium between Halemaumau load, outflow weighting in the desert, and viscosity of epimagma crystallization in the pit, and in the new dome Mauna Iki that piled up in the Kau Desert, and in the dike beneath.

The country was wider and higher by the tumescence of the rift fillings. Probably this was absorbed by the outward movement of the seaward fault blocks. If so, the sudden deep splitting with earthquakes of the early morning of November 28 hinged at the surface line of the crack, with lateral thrust and upward lift by the magma wedge; the noon outflow opened the hinge itself to gaping, and after the pulse of recovery December 22 surface gaping against gravity, due to the inward pressure of the mountain, was propagated southwest. This mechanism tells the story of all the Kilauea and Mauna Loa wedgings and most of the earthquakes. If the student of "dynamical" geology reads the facts of this and similar episodes, he will learn much of the volcanology of craters. He will learn that flank lava flow depends on a gravitative relation between a transecting rift belt and height and differentiation of crateral lava, wedge rupture, pulsating effervescence, and both a hydraulic system and a gas pressure-solution system. (*See also* Weight of crateral wedge, Bulletin, 1924, p. 121).

MAPS AND PROFILES OF HALEMAUMAU, 1920

MAP OF FEBRUARY 17, 1920 (Pl. 80 a)

The descriptions in Part 2 will suffice to carry the reader to the next map of February 17, 1920. Halemaumau was destined this year to carry forward the pulsation mechanism with very great development of crags of epimagma (Pl. 80) and with summer and winter (1920–1921) high levels. The exaggeration of the epimagma upthrusts was to reach extraordinary proportion in 1921 (Pl. 76). The control of the rising of 1920 that culminated in the early summer was the recovery of the pit lava column as the Kau Desert outflow gradually plugged itself and dwindled, so as to back up the lava into Halemaumau pit (Pls. 34f, 40) once more. This was followed by the usual moderate subsidence that follows summer solstice and the customary very rapid rising of winter solstice. The desert outflow ended about August, with pahoehoe crusting over and concealment of all incandescence.

The map of February 17, 1920, exhibits the remnants of the ring-pool as border ponds and blowing cones, but the central lake had developed extensions during January northeast, southeast, and southwest, so that the ring-crag had divided into three sectors as in 1919. The north crag was still the dominant peak standing 84 feet above the lake. The latter 267 feet below the northeast rim of Halemaumau had become adjusted to the desert outflow and was recovering. The formation of epimagma was restoring uplift by sectors, and much of the inflow of pyromagma appeared to be up the radial cracks about the center. The record shows that the lake gained on the crags February 13–19, the rate of rising was 4 to 5 feet per day, and shoals of epimagma emerged in the central part of the lake; these were adjacent to or between three radial lines of fountains ending at north arm, southeast arm, and southwest arm, and these had begun their development as crevasses through the encircling crag mass. The island shoals were produced by combined lifting of the bottom sectors and piling up of foundered crusts. The crags east, northwest, and southwest exhibited centrifugally inclined terraces (Pl. 40b) which marked stages of tilting of epimagma sectors just as in 1916–1917 (Bulletin, Fig. 3, April 1920). Between the glow from Halemaumau and the brilliant flows from the new Mauna Iki in the Kau Desert, Kilauea was so bright that the light was seen from ships on the distant ocean. The lava column was rising so that lake and crags alternated in their spurts, the north crag gaining 14 feet on the lake February 9–13, and the lake gaining 6 feet on the crag February 13–19.

February 17 the island had risen so as to stand 10 feet above the liquid, a cascade *from the lake had widened toward the southwest grotto,* the southwest crag showed numerous raised shore lines tilted toward the north, and the lake had flooded a new region at the west pool. The northwest bay was shallow over a sector of epimagma. (*See* map of May 14.)

At the end of February both Halemaumau lava and Kau Desert flows showed increased vigor. The crag and lake continued alternations of rising, the total movement being a gain of about 20 feet in a week, the east island became a peninsula, and the border ponds were becoming crowded out by the centrifugal tilt of the sectors of epimagma, so as to be replaced by blowing cones. The epimagma was growing in area at the expense of the lake. The cascade at the southwest was clearly a sinkhole for the circulation, and the source wells appeared to be mostly in the sectoral cracks, in marked contrast to the boiling up of the peripheral wall pond in December.

MAP OF MAY 14 1920 (Pl. 80 b)

The spring rise produced more islands, extinguished the remains of the ring-pool, created a new south crag by lift of the ground between the southwest arm and southwest grotto, and greatly changed the shape of the western and northeast crags. These transformations in 3 months show how pronounced are the streamings upward of filaments of the epimagma as definite movements of the lava column. The maps of February 17 and May 14 exhibit the character of the many changes that occurred in 1920, otherwise described in Part 2 and illustrated in the Bulletin of the Observatory.

Rising lava the first week of May was followed by lowering that began May 11. The liquid lava was 121 feet below the rim on May 8 and 147 feet on May 14. The west crag, which had started as an island in March, was now the tallest peak and stood 119 feet above the central lake. The circulation now appeared to be resuming its old adjustment of inflow and highest level at the northwest, the convection streaming to lower level and sinkholes south and southeast, for the southeast arm was lower than other parts of the lake; the cascade locality of the southwest grotto of February still showed itself, but at the end of the rearranged southwest arm. The cascade in the southwest arm had become invisible owing to rising lava on May 5, becoming visible again during a sinking spell on May 11. Blowing cones were in evidence when the lakes were rising and little heard from during sinking spells. During all this time the Kau Desert flow continued to spread to the south and east. The rift line underneath Halemaumau pit passed through the southwest border cone, the cascade, and the central lake. (*See* 1919 maps.)

The week after May 14 showed both crags and liquid lava lowering, and the cascade in the southwest arm on May 18 changed to a current into a grotto by the filling up of the cascade pot. By the end of the week the crags tended to break down, and the pit became fumy. The story of the remainder of 1920 and the great flooding rise of the lava in December may be read in Part 2.

MAPS AND PROFILES OF HALEMAUMAU, 1921

MAP OF JANUARY 4, 1921 (Pl. 80 c)

The superb movements downward of the lava column in 1921 may be seen in Plate 76b, and its sequel in the impressive downplunge of 1922 (Pl. 76c) shows on a smaller vertical scale the way in which the epimagma gradually disappeared as crag masses, when outflow on the east rift took control. These outflows of May 1922, August 1923, and May 1924, with Halemaumau recovery in the intervals (Pl.74), still maintained epimagma in the crater as exhibiting floors, marginal benches, wells, and sinkholes, but the pyromagma dominated the surface expression of the Halemaumau bottom with pahoehoe coatings, and the lift of vertical filaments of epimagma which was so conspicuous between 1917 and 1922—excepting the overflow period of 1919—was replaced by a different habit as the 1924 crisis was approached. The year 1921 was the greatest crag maker in the history of this cycle (Pl. 84b, map of Kilauea).

The high level of January 4, 1921, had drowned most of the crags of 1920, leaving the northeast peak dominant and the lakes nearly level with the Halemaumau rim as in 1919. The year 1921 was ushered in by a rise of 200 feet in a month whereby liquid lava overflowed the rift cracks outside Halemaumau southwest December 27, 1920, and this flow was spreading on the southwest Kilauea floor. Maintaining this outlet at what through these years was called the Red Solfatara, the liquid lava in the pit on January 1 held itself level with the lowest part of the rim, overflowing and building up the northeast margin. The northeast crag peak on January 4 stood 90 feet above lake level (Pl 76b) and had risen faster than the pyromagma. (*See* illustrations Bulletin, December 1920.) The profile shows that the lakes subsided a few feet below the overflow of January 1 (Pl. 80c). The facts of source well southwest and sinkhole northeast, and the shallowness of the lake, are not hypothetical but are based on evidence revealed when the liquid stood lower relative to epimagma; the mechanism of its concealed conduits, shoals, uprisings, and cascadings can only be interpreted by prolonged observation, and these profile sections are diagrammatic expression of results of such observation. The significance of the wall crack where these wells occur was never clearer than at this time, for all border pools developed centripetal streaming away from the wall in those places where gas-charged lava was rising and the east pond developed the greatest cascades, on several occasions.

The straight northeast side of Halemaumau is a fracture line, which had developed before November 1919 and met another new fracture bounding the pit on the northwest, and at their meeting point north was the origin of the Postal Rift flow of August 1919. Between these two lines were the shelves of downsinking of the maps following the November 1919 crisis, and these shelves were now, in January 1921, all drowned under surface lava. The depression contour at the north indicates how the lakes had built up their cups, so that east and west ponds had for weeks maintained levels above the north floor of the pit and had flooded that floor repeatedly.

The southeast pool had only recently become separated from the central lake by uplift of the shoal between the two. The contours show how the northeast crags had been lifted and tilted eastward, and three low eastern summits by this process of overturning had become trivial features, whereas these had been dominant peaks in September 1920. At that time the present peak had been a low overflow bench of the lake floor. The west crags had a similar history, and a new point was now lifting and tipping westward. Broken lines on the map, marking cracks, indicate some boundaries between sectors of the epimagma, which execute these tilting uplifts, the center of the pit being generally the locus of maximum swelling. Along the crack lines tunnels of liquid lava connect lakes, and over these were formed the cones shown, during such a high-pressure spell as this map records. The wide flat areas are overflow floors which were almost incessantly flooded in December 1920.

The scene at Halemaumau was now much more brilliant and gas-active than the outflow period of July-August 1919. Within a ring of low cliffs 5 to 25 feet high, one saw five boiling lakes of fiery lava surrounded by a circular flat of fresh silvery flows, and on one side stood the great crag, an uptilted block of shore matter. Other smaller crags dotted the topography, channels connected some of the lakes, and blowing cones over fissures threw up molten spray and splashes of glowing melt. The burning gas bubbled out at hundreds of fountains amid rushing currents which tended to focus toward the southwestern rim of the pit and to set up occasional whirlpools.

Down the slope outside Halemaumau in this direction two large cones had formed over a crack (at the Red Solfatara) which sent floods of lava into the marginal lowland of Kilauea Crater. This flow was now running so as to form a slag heap with a crusted pool on top spreading east and west over the southwestern part of the Kilauea floor for a length of $\frac{3}{4}$ mile. At the front of the flows lobes of live lava were spreading forward. Through the southwest rift crack Halemaumau was feeding the outer cones and the slag heap, with the slight fluctuations in its own upbuilding. While the outflow was to the southwest, there may have been some reversal in the sinkhole circulation of the pit. Subsidence followed about January 17, and the outflow stopped. Such reversals of convection are of interest for physical interpretation of the probable depth of the top of the hypomagma.

The high level of January 1921 produced larger lakes by caving away of margins after adjustment to outflow was complete, indicating that overhang and bridging by crust had developed during continuous rise. There was probably correlation between the squeezing up of the large crag mass and the heavy weighting by overflows and lakes of the rest of the pit. The liquid lava foamed up at east-central wells and at the wall crack so as to show standing fountains, cones, and blowing vents and chasms, but when subsidence began some places became the focus toward which cascades poured inward.

MECHANISM OF PYROMAGMA

This was the time, as recorded in Part 2, when gas was developing, escaping from solution, even in the skin of a blister (Pl. 73c) up to the instant of solidification.

After each gush of lava overflow inside the pit the direction of flowing changed, sometimes completely reversing its course within 12 hours. Thus the east pond would send an overflow from its bank toward and into the southeast pool, finding a downgrade in that direction. On another occasion a rush of overflow from the west pond poured around the northern inner border of the pit into the east pond and beyond. Later the same day the southeast pool overflowed northward toward and past the east pond and sent a great river of lava circling the crag mass toward the northwest. Each well fed by the wall crack or other fissure below apparently becomes a center of tumescence during a rise, and possibly the others become centers of shrinking in the marginal epimagma after the internal pyromagma has been relieved of gas heating by overflow.

MECHANISM OF EPIMAGMA

When subsidence began in January 1921 the number of fountain bubblings dwindled. A general jostling of the crag bodies occurred, and the floor of the pit sagged in a concentric valley near the pit wall. This suggested that withdrawal of matter below began along the wall crack—the place where there had been maximum upwelling of pyromagma during the high pressure. These phenomena of motion in the epimagma began while outflow on the outer Kilauea floor was still strong. When outflow stopped there was a slight reaction of rising in Halemaumau before the main January subsidence began. The fault block from a cliff of the east crag mass slipped down into the pool and proved that the liquid was 25 feet deep and that the epimagma of the bottom was capable of supporting a load of solid basalt. This agreed with the evidence of many other occasions when slides or talus have fallen into the lakes where they find a shallow bottom and then heap many tons of rock matter above. Although solid crusts and fragments of basalt always sink in pyromagma, no measurement the Observatory has ever made has shown a cliff or crag foundering in epimagma paste—that is, in the lake bottom material encountered by sounding in 1917. There have been many occasions, however, when the weight of new flow accumulations appeared to correlate by subsidence with adjacent uplift of other portions of the epimagma, somewhat like isostatic balance or the squeeze of paste.

The measurements of the 11 days preceding December 29, 1920, showed the lake rising 67 feet, averaging 6.1 feet per day, while the newest summit of northeast crag rose 91 feet, averaging 8.3 feet per day. This showed the relief of the crag above lake level to increase from 52 to 72 feet. The rate of rising decreased sharply December 27 when the first outflow southwest occurred on the Kilauea floor. On January 4 the lake was 30 feet below datum, the northeast crag 54 feet above; the rising record of lake and crag was much the same for the first half of January, but with the lake sinking after January 12 there was increased relief for the crag. Height of crag above lake was:

January	*Feet*
4	84
8	83
23	102
31	109

MAP OF FEBRUARY 8, 1921 (Pl. 81 a)

Our succession of 1921 maps (Pl. 81) shows distinct increase of relief of crags and complicated subdivision of the lakes during the year. This in spite of the fact that the surveys of February and March showed very high levels of overflows. The first of these is indicated by the map of February 8 (Pl. 81a) which may be compared with the columnar levels of Plate 76b. This map will serve for the general conditions of the March rise, except that in February-March 1921, as on the map of February 28, 1918 (Pl. 78b), there were overflows on all sides, and in 1921 the liquid area was more extensive. Subsidence ended on January 31, 1921, and during the first week in February it was rising 3 feet per day. Measurement of February 8 made the mean lake level 27 feet below the northeast datum station, and the relief of the northeast crag peaks above the lakes varied during the high-level episode as follows:

	Feet
January 31	109
February 8	96
" 20	100
" 24	105

Adjustment was reached when outflow on the Kilauea Crater floor at the rift cones again occurred, the flowing continuing from February 8 to February 20, when the liquid lava in the pit lowered only 5 feet in 12 days.

The quality of the activity was restored to the January condition with the marginal lake developing scores of fountains and spatter grottoes of live lava, and inner walls of the cups of the five principal pools stood 5 to 15 feet high. The lakes rising around crags and tabular elevations of epimagma, which had broken down with the subsidence, created new islands around the tumbled remnants. The large cone that reformed west of the southeast pool threw up jets of lava 40 or 50 feet high. The flexible crust on the lake was inflated by the gas into huge balloons several feet across that migrated with the currents and collapsed quietly. The second week of February produced the uttermost of splendor in the fire pit (Pls. 43, 44), the outer flow was again flooding the southwest part of Kilauea Crater, Halemaumau developed hundreds of lava fountains approachable to within a few feet, various craggy heights divided the five lava pools, hissing gas spiracles (Pl. 73a) showed green and violet flame, and rushing torrents of golden brilliancy swept from one lake to the other emitting thin fumes of red, brown, and blue that in the evening light made the scene exceptional. The glow on the fume cloud at night was yellow and unusually bright, and where the fountains were largest, in the east and west ponds, the current was swiftest. The marginal ponds tended to stream inward, but the center lake had a quiet crusted spot whence the streaming was outward.

An island in the southwest lake rose gradually as a shoal from the bottom epimagma. It arose from a crusted eddy amid the currents, developed a plateau surface, and then tilted sideways. At the north a spatter heap 9 feet high was built in fantastic shape, until it resembled a peacock. Outside Halemaumau on the rift the new flow cone southwest formed a boiling pot shaped like an armchair (Pls. 34a, 40c), out of which the source lava of the flow shot down the slope like a sluiceway.

The fountaining in the lakes was carried along by the streaming current, showing that concentration of bubbles in the glass was itself transported. Hundreds of centers developed a "bubble and spurt" quality, whereby each individual doming burst would fling up a slaggy rope so that these groups of fountains resembled flocks of fiery swans. Remarkable silence was a feature away from blowing cones.

At the end of February there was again lowering, and after the outflow stopped the fountains diminished, a tunnel in the southwest Kilauea floor where the lava had been seen flowing became dark, and windows in the outside source cone revealed the interior as a large glowing chamber lined above with long "grapevine" stalactites formed by the hot gases glazing the ceiling by secondary melting. Around the outside source cones at the head of the flow, which stood over the rift zone, patches of white, pink, and yellow sulphates, sulphur, and selenium several inches deep were rapidly deposited by vapors on the fuming substance of the fresh flows, and this new basalt was thus decomposed by the acrid gases with remarkable rapidity. These rift cones were the scene of a succession of experiments to measure temperature and viscosity (Bulletin, February 1921).

The following is the journal of February 8 (Pl. 81 a):

"It was evident at 10:00 a.m. that Halemaumau had now entered a second eruptive episode of high pressure similar to the December crisis. During the previous night the escarpment bounding the northwest cove on its west side had risen seven feet and formed a new crag. Lakes were rising very rapidly so that southwest arm stood only two feet below the border ledge. In the forenoon the west and central lakes were in view from the Observatory and in evening East Pond was also in view and West Cone could be seen spouting. East Pond stood three feet below December overflow rim. At 11:00 a.m. West Pond was overflowing northward, and southeast pool overflowed its ramparts on southeast side. East and West Ponds occupied cups at the top of built-up slag heaps, with long slopes leading down to a lower region at the north floor (depression contours). Everywhere there was hot fountaining of the "bubble and fling" type, and balloons, blowing cones and building of spatter margins attested gas inflation. There were almost no sinking spells, and an incessant mild roar was heard of whirlwinds and blowing orifices. Long coves of the central lakes had formed in the northwest and northeast chasms. Small pots surrounded by crust had formed in the northern extensions of East and West Ponds. In early afternoon flows poured from East and West ponds to north floor.

"Outside of Halemaumau the two southwest rift cones were flinging out spatter lava so that the lower one had built a new driblet cone on its west side, covered with glassy filaments, and from this a short flow had cascaded into the window of a tunnel. Flows only a month old were discolored with fresh white, pink, yellow and orange salts partly tasting of alum. About 6:00 p.m. the lower rift cone first opened and gave vent to a flow which covered several acres on top of the December flow. The streams made a brilliant display coursing over the southwest part of Kilauea Crater" (Pl. 84 b).

MAP OF MARCH 14, 1921 (Pl. 81 b)

The greatest gas crisis of overflow of actual rim at Halemaumau in the history of the Observatory was that of March 1921. (*See* Part 2 and "Discussion of special features", Bulletin, March 1921). For the maps of Halemaumau before, during, and after the crisis, that of March 14 shows the dull period of the days just before the sudden rise of March 18; the maps herein of January 4 and February 8 show the appearance of general conditions of overflow that correspond to the time of repetition of such crisis from March 18 to March 25, and we shall see in the maps of April 4 and August 13 the lowering that ensued.

The second week in March produced slowly subsiding lava, both lakes and crags lowering 1–2 feet per day. The activity became remarkably sluggish, the lakes being mostly crusted over, with only 20 or 30 fountaining places in the whole area. The islands enlarged, and new islands appeared, as shoals were revealed by receding lakes. One island toppled over, and its side broke away. Numerous avalanches fell from the crags, sending up spectacular clouds of red dust. A western peak full of vaporing cracks appeared to surmount some sort of cavity beneath, dense masses of fume boiling up incessantly here from a huge overhanging block where rocks were tumbling. The glow above the pit at night was dark red, brightening during the week. The flow cones of the outside rift remained vigorous gas vents and showed glowing stalactites of the wormy type (Bulletin, 1921, Fig. 18).

On March 14 the lakes were rising, rocks fell near West Pond, and East Pond was rising and overlapping its shores. A small open patch was streaming to the south channel of the southeast pool, elsewhere the pool was crusted with hissing from the margins. East Pond had open lava moving northward from a bright edge to fountains against the west bank, and one of its islands had become a flat peninsula a foot high, against the northeast side of the pool. Central lake was streaming south on the east side of the islands.

On March 16 the small central islet swelled upward from the lake bottom to become an immense hill (Pl. 45d), with the original little island standing like a thin-stemmed mushroom on top. This mass stood 40 feet above the lake with the summit toadstool leaning, rounded, black and smooth, with shore marks on the southern half dipping southward as if overturning in that direction. The northern part had four promontories and filled a great part of the lake area. It all belonged to the southwest sector of epimagma. This upheaval was a preliminary of the tremendous lava gushing of March 18. (*See* photographs in Bulletin, April 1921.)

From March 8 to 14 the lake and northwest crag lowered 9 feet in 6 days, averaging 1.5 feet per day; and the northeast crag sank 11 feet, averaging 1.8 feet per day. With the spectacular rise of the middle of March the lift of liquid lava exceeded that of the crags from the start, though the crags seemed to rise faster because of the sudden upheaval of the new island and other peaks, and the quiet surface of the crusted liquid. In 3 days (March 14–17) the lake rose 60 feet averaging 20 feet per day, and the next day it rose 44 feet and overflowed. In the March 14–17 interval the northeast crag rose 24 feet averaging 8 feet per day, and the northwest crag 17 feet averaging 5.7 feet per day, followed by a rise the next day of 22 feet, while through some readjustment the northeast crag lowered 8 feet. Then during the high-level week, with continuous overflow, Halemaumau lava lowered slightly, the crags more than the lake. The rift flow outside Halemaumau filled the southern embayment of Kilauea Crater and penetrated a gap in the border ridge so as to flow out into the desert.

The third week of March produced an equinoctial eruption that made Kilauea more spectacular than at any time for a decade (Pl. 44). Halemaumau was one great overflowing lake with islands (Fig. 16, Bulletin, April 1921). The gas release which followed the overflowing produced three sinkhole caldrons at the arms of the lake, which developed large clusters of roaring fountains, hot greenish-brown fume, inrushing cascades, and upthrown slaggy flings that formed ramparts. The actual whirling movements of air carried shells and fragments of glowing basalt hundreds of feet into the air and several hundred yards from the pit. Mauna Loa showed a "pine tree" cloud. The new rim of Halemaumau was almost unrecognizable. Showers of grit and spun glass fell to leeward. The eruption continued steadfastly with pit in adjustment to outflow, and some of the crag islands began to disappear. The crags were all coated with a shell of vitreous slag.

The end of the month started a rapid sinking away of the lava column to the 100-foot level, whirlpools and shifting sinkholes formed, crags and islets increasingly emerged, fume grew thicker, and lines of traveling fountains became conspicuous. The roar, glow, and heat dwindled. The flow on the Kilauea floor ceased, impressive underground chambers hung with glowing stalactites were revealed at the two southwest source cones, and banners of pale flame were seen there.

MAP OF APRIL 4, 1921 (Pl. 81 c)

From April 1 to 6 the lake lowered 38 feet, the south crag 28 feet, and the northwest crag 23 feet. The relief of the south crag increased from 78 to 88 feet and of the northwest crag from 69 to 84 feet above the lake. The faster the lake went down the more its subsidence exceeded that of the crags. The statistics of the diversified movements of epimagma and pyromagma from January to April 1921 will be found in the Bulletin, April 1921 (p. 79).

On April 4, marginal ramparts and shelves were breaking away, avalanches fell from the northeast wall of Halemaumau, the ground trembled, and some of the survey stations had been buried under new ramparts, submerged under flows, or spattered, or the adjacent ground was newly cracked. The outside rift cones were sending up semitransparent cauliflower clouds of hot gas. Inside the pit the heaviest vapor rose from a tumbled area at the north. Streaming was dominantly eastward and westward from the center, islands were enlarging, and though fountaining had decreased there were still dome fountains, continuous fountains, bubble fountains, whirlpools, and cascades.

Heat from the open lakes decreased throughout April, and the glow above the pit lessened. The rift cone wells outside kept up a bright orange glow and maintained a stalactitic glaze, while pale flames played around the orifices, and sulphurous gas was given off. The upper cone was an open glowing oven 9 feet high and 20 feet across. As these wells had demonstrated for many months a direct hydrostatic connection with the liquid lava of Halemaumau, it appeared certain that now as before there was liquid lava about 200 feet down in the wells. The heat therefore was maintained by burning gas for a height of 200 feet, more or less, in wells 10 to 15 feet in diameter. There was little apparent fluctuation in the glow, and stalactites in the upper cone oven, intentionally broken off, reformed in a few days by the melting of a glaze through the heat of the gases.

The fume from these vents was pale and bluish, rising rapidly. It did not produce a great quantity of sulphates such as had been so rapidly formed over the rift in January and February. Stain formed of whitish and rusty insoluble salts, but nothing to compare with the former condition. On both occasions, there were red-hot vents of gas close at hand and fresh flows for gases to act upon. In April some ingredient or acid condition for gas action on the rock was removed, in contrast to the active gases which decomposed the rock all through the autumn months before the strong risings and overflowings of the winter. The subsiding lava of April had lost some chemical power of its gas, and this co-ordination of gas composition and rising eruptivity appears important. In June 1921 the southwest rift chamber became dark (Part 2), then air was admitted by the lowering in Halemaumau, intense oxidation and glow followed, and with the rising lava of the autumnal equinox the gas changed its quality, and the Red Solfatara again became a place of deposit of sulphur and alum.

MAP OF AUGUST 13, 1921 (Pl. 81 d)

The map of August 13 exhibits the quality of the low level that followed the spring crisis and also the increased size of the crags at the expense of the lakes. The remarkable domination of the crags for the September rise of this year may be seen by comparing in the Bulletin Figure 27 of August with Figure 32 of September.

If we take the last day of each month from January to July, the general progress of the lava column was down. The flurries of overflow the first 3 months do not alter this fact. August and September showed a much greater movement up. This is recorded by the following table exhibiting the mean change of lake level and crag level for the last day of each month, as compared with the last day of the preceding month. Minus sign means down, and plus sign means up (Pl. 76b).

	Liquid lava *Feet*	*Crag lava* *Feet*
January	−32	−7
February	−15	−21
March	−13	−61
April	−145	−93
May	−48	−53
June	−16	−30
July	−22	−14
August	+119	+118
September	+138	+158

As before the pit was intimately connected with the live wells of the southwest rift just outside on the Kilauea floor. The lava inside this southwestern rift had risen faster than the lava in Halemaumau. Glimpses down into the black void under the upper oven revealed crusted glowing lava 100 feet beneath, occupying a big chamber lengthwise of the rift. Its lava surface stood fully 200 feet above the liquid lakes in Halemaumau, gases were bubbling at the glowing edges, and this difference in level, with the two columns directly connected through the well-known tunnel (Pl. 45b) below, showed that for the same inflation a smaller quiet well will hold a higher level than a larger one where the liquid is fountaining freely.

During this second week of August the lava lake had risen 26 feet since July and stood 307 feet below the northeast rim datum station. Seven or eight fountains were noisy, in some of the pools there were streamings, and small avalanches were common. The chasm of the southwest rift inside the pit was full of black lava tricklings inward away from Halemaumau, and it is this chasm which emerges outside at the rift wells.

The surveys showed that from July 31 to August 13 the lake rose 25 feet in 13 days, averaging per day 1.9 feet, while the south crag rose 22 feet averaging per day 1.7 feet. In 17 days the relief of the northwest crag above the lake increased from 106 to 118 feet, and in 13 days the relief of the south crag decreased from 114 to 111 feet. This change in domination by rising of the different vertical filaments of the epimagma made it necessary on the columnar diagrams (Pl. 76) to indicate by the letters NW, W, S, and otherwise, which crag is being used as the type to show height and relief of the epimagma.

The week following August 13, 1921, brought the liquid lakes to depression level

290 feet, crags lifted new promontories into view, an island joined an adjacent peninsula, and a cove of the central lake became a pond. Ten fountains were the maximum number counted, and hissing cones built up on crust surfaces.

NUMBER OF FOUNTAINS

In both March and September 1921 the number of fountains increased strikingly at the peak of the rising movement and declined thereafter. Thus in September we have the following numbers of simultaneous fountains, actually counted each day.

	No. of Fountains
September 9	2
11	15
13	12
14	20
16	50
18	55
20	90
21	147
22	90
23	70
25	45
26	23
27	20
28	10
29	5

The liquid reached its upper limit September 20 along with the waxing of light and heat for the pit as a whole, and there was coincidence of the crisis with equinox. The harmonic microtremors of about 0.7 second period had increased in the spring eruption at the Observatory seismographs from very slight to very strong on March 18, just when the fountaining eruption began. In the autumn these tremors began to appear after September 11, notably increased on September 18, continued with moderate force until September 21 when the fountaining at Halemaumau was at its maximum, and thereafter decreased with the decline of the fountaining.

On the other hand, the rapid convectional streaming across the lava lakes was not so conspicuous in September as it had been in March. Even at the peak of the rise September 21, when more than 100 fountains were bubbling, the lake surfaces tended to stagnate, and the fountains formed in lines at separate puddles irregularly spaced, with none of the rapid-river effects seen in March.

The spurt of the crags in September was impressive and was not followed by any gush of liquid. Individual hardened crag blocks rose on one side and tipped over, as though each block surmounted its own paste tube and became overbalanced, scaling off in avalanches and leaving a sharp peak. The alternation between rise of northwest and south peaks went on in September, and in contrast to August the south crag rose excessively. This produced an appearance as though the whole circular cake of epimagma were overturned northward, by reason of the extreme upward thrusting of the southern half of the upright cylinder. Where the flood of pyromagma in March had been at the expense of the epimagma, the reverse was now the case.

SURVEYS OF HALEMAUMAU, 1922

PROFILES OF 1922

Kilauea lava subsided three times, with intervening rises, during 1921–1922, the last lowering being the greatest engulfment of the Halemaumau walls that had yet occurred in the twentieth century. (*See* columns of Plate 76, which show lowerings in summertime of 1922, 1923, and 1924, these occurring in May of 1922 and 1924, the last producing steam-blast eruption, and both leaving Halemaumau pit floored with a funnel of debris.)

The collapse during May 13 to May 27, 1922, enlarged the pit from a diameter of 1400 feet northeast-southwest to 2000 feet, with the bottom a cup of talus 861 feet below the rim. May 28–29, came short-lived outflow in Makaopuhi and Napau pits of the Puna chain of craters about 9 to 12 miles from Kilauea, unquestionably marking a drainage along the eastern rift from Halemaumau. This is described more fully in Part 2, and the increasing sudden drops of Halemaumau lava from 1919 to 1924 are exhibited along with a curve of the lowest levels reached (Pl. 74a, b).

The column diagrams of Plate 76 c for 1922, compared with d for 1923, show how the phenomena of crag elevation relative to liquid lava diminished and disappeared during 1922. For maps of the pit the conditions of the first 5 months of 1922 were of the same quality as 1921, and the recovery by large flat pools and floors is sufficiently illustrated by the maps of 1923 and 1924 (Figs. 7–13). Halemaumau was dormant after the May collapse in 1922 until lava burst from the top of the talus against the cliff and began to fill the pit July 17 and again September 2, 1922.

MAPPING OF 1923–1924 ACTIVITY

MAPS OF HALEMAUMAU, 1923 (FIGS. 7–12)

Pulsations of rising (Pl. 48) reached a level 127 feet below Halemaumau rim July 4, 1923, followed by a big subsidence in August accompanying outflow east in the forest near Makaopuhi and reproducing on a scale less intense the relations of 1922 (Fig. 7; Pl. 76). The August drop left a rock bottom of broken epimagma 565 feet below the rim. The outflow west of Makaopuhi spurted up a long crack in the forest about a mile in length and endured from August 25 to 30, spitting frothy lava into tree tops (Pl. 47), depositing sulphur, and generating irrespirable steam poisonous with sulphuric acid. The outflows were like pools in the jungle, not more than half a mile long from northwest to southeast. The source crack trends northeast between Alealea pit and Makaopuhi and ends against the hill Kane-nui-o-hamo. It is one of the bench fractures between Kau Desert and Chain-of-Craters (Pl. 85).

MAP OF SEPTEMBER 22, 1923 (FIG. 7)

Inflow recovery occurred September 4, 1923, under the southeast wall of Halemaumau. The depth of the pit decreased, mainly by accumulation of lava inflows, from 565 feet depression to 400 feet at the end of the month. A second source of upwelling lava had appeared in the southwest center of the pit September 6, a third source at the south September 11, and a fourth at the north September 19, these all appearing as conelets on the map (Fig. 7). At the time of survey the lake was 440 feet below the rim and was rising, the sources were building cones, the fountains were small, and the fume was very thin.

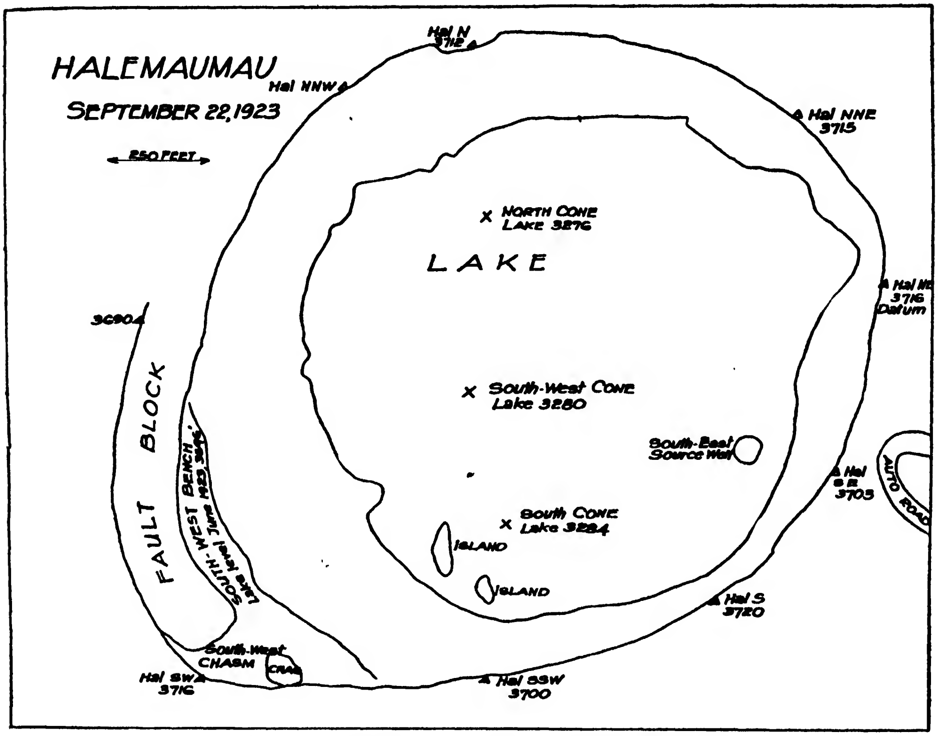

FIGURE 7.—*Halemaumau surveys, September 22, 1923*

Showing source cones developed in lake of their own accumulation after the lowering and Chain-of-Craters outflow of August. Depression southwest cone 436 feet.

Halemaumau was left by the collapse of May 1922 an oval with downbroken fault block and a craggy pinnacle at the southwest, and a chasm in between where the Red Solfatara had been between 1918 and 1921. The base survey of July 6, 1922, indicated mean elevation of five rim stations to be 3714 feet above sea level, a loss of 18 feet from mean height of the rim before the collapse of May 1922. The new stations were in positions on the floor of Kilauea approximately 100 feet farther back than the pit rim of 1921, which had caved in to that extent. On the southwest side toward Red Solfatara a band of 1921 rim 500 feet wide had been engulfed. From road terminus southeast, going around the pit clockwise, one encountered a small remnant of the south pressure ridge, then a slag heap remnant of 1919, then the pinnacle ledge standing out like a huge castle, and finally the fault bench extending the whole length of the west side of the pit, with crevasses emitting scorching hot air from the tunnels below leading to Kau Desert. The northeast region was a flat remnant from the overflow pool of March 1921. East were hillocks and driblet heapings that had been a slag-heap center in 1919. Oblique dike intrusions dipping inward concentric with the pit were visible in the inner walls that were stained with solfataric deposits especially at the south. Dimensions were 2000 feet northeast-southwest, 1486 feet northwest-southeast.

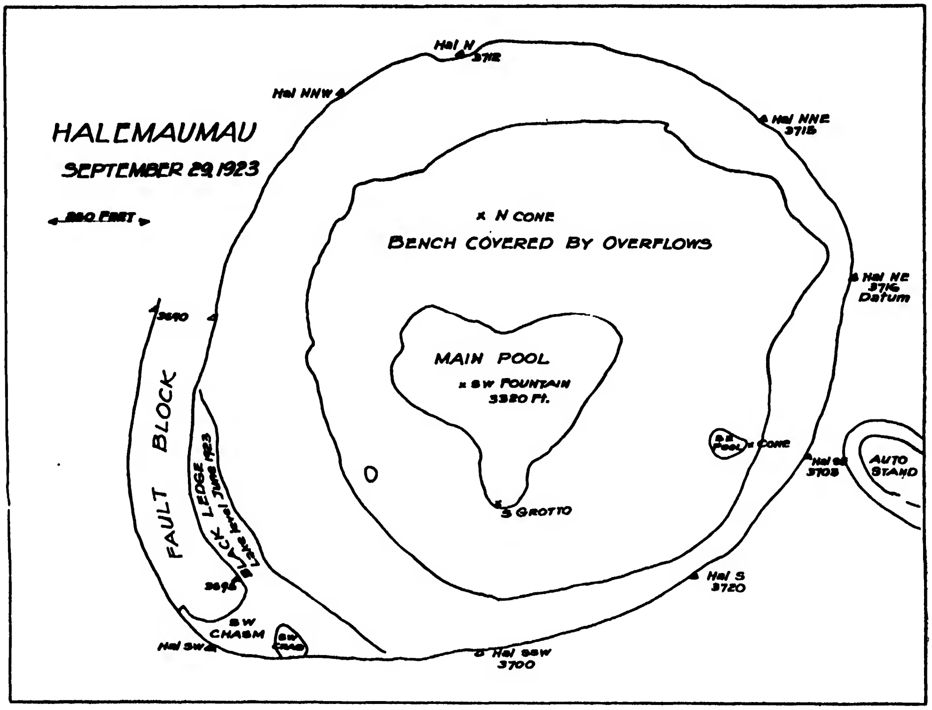

FIGURE 8.—*Halemaumau surveys, September 29, 1923*

Showing two pools within overflow benches. Depression main pool 396 feet.

MAP OF SEPTEMBER 29, 1923 (FIG. 8)

The shallow lake had risen 42 feet in a week and contracted to a small triangular pool enclosing the southwest vent as a fountain. A southeast pool was full with the cone ejecting a small flow. Strong streams poured east and west from the north cone. Fume came from the southeast cone. At 4:00 p.m. the triangular lake rose and overflowed its southeast bank while the fountain threw up lava slop 30 to 40 feet.

MAP OF OCTOBER 11, 1923 (FIG. 9)

This map shows the main lake risen 50 feet since September 29 in 12 days. The main pool was 356 feet below the rim, the north pool 8 feet less. At the time of mapping there was temporary subsidence, with a large chilled sunken area at the east, and the east arm of the main pool had become a sunken region with a rapid stream flowing into it. The southeast cone was pouring out a small flow on the bench which at times cascaded into the main pool. Four source fountains were somewhat active, the north cone was hissing, and the west wall of the east arm was made of aa lava which glowed like a coal fire.

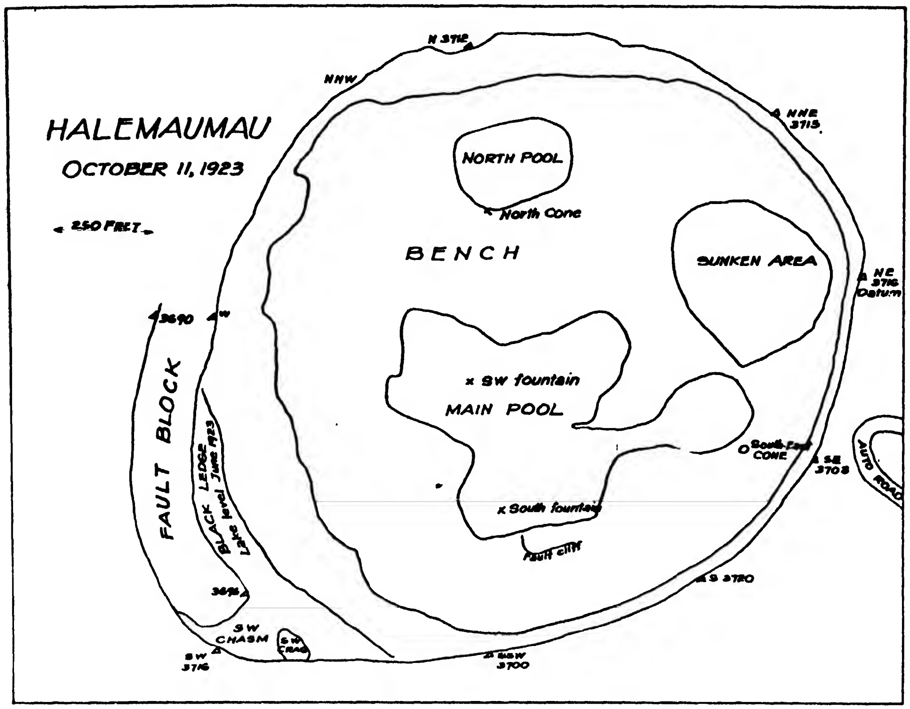

FIGURE 9.—*Halemaumau surveys, October 11, 1923*

Showing merging of these, development of north pool, and of sunken area in epimagma northeast. Depression main pool 356 feet.

MAP OF OCTOBER 17, 1923 (FIG. 10)

Since October 11 the north pool had risen 2 feet, the main pool 18 feet, so that the latter was now the higher; the north pool stood 346 feet below the northeast datum station, the main pool 338 feet. There had been sinking since October 13 making three islands appear, now joined to the east side of what had been the lake margin at the higher level. The two small islands shown were new. The fountaining was very weak. As a whole the lake was 100 feet higher than on September 22.

MAP OF OCTOBER 27, 1923 (FIG. 11)

At this time with general rising there had been lift of benches of epimagma, a definite pool had developed at the southeast, a big inflow had occurred there on October 25, and the shore line of the main pool had tilted southwestward. All three pools were now full and overflowing the bench, the north pool southward, and the east pool northwestward. The north pool had built high ramparts around its north side so that it stood on a hill. A southeast chimney sometimes belched strongly.

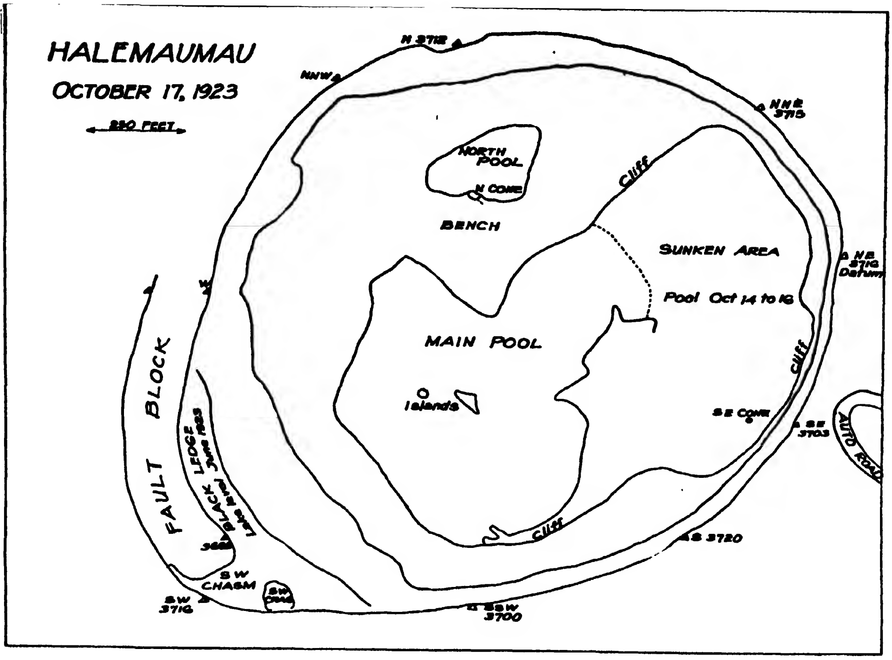

FIGURE 10.—*Halemaumau surveys, October 17, 1923*

Showing extension of inner cliff around sunken area. Depression main pool 338 feet.

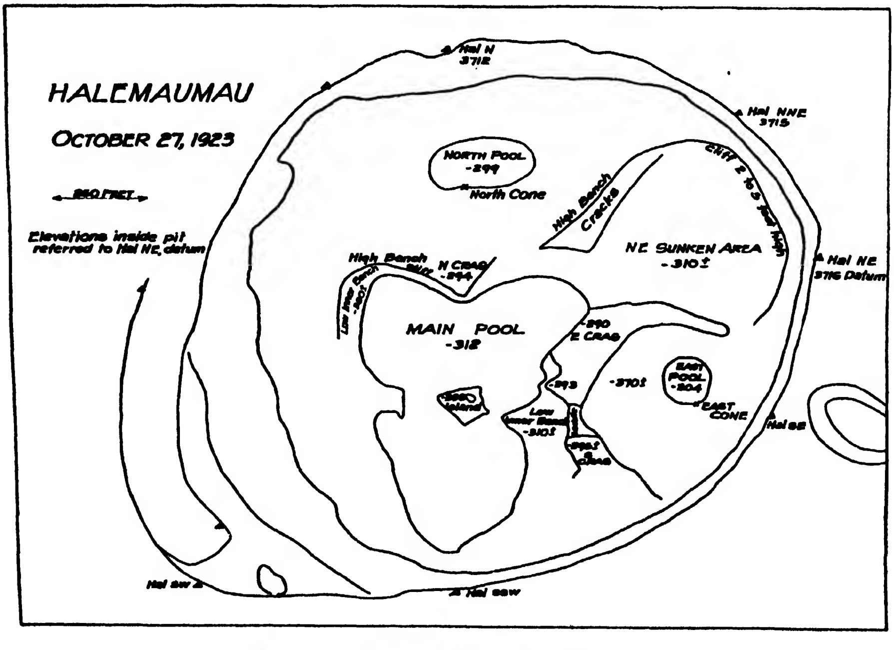

FIGURE 11.—*Halemaumau surveys, October 27, 1923*

Showing development of three pools and some elevated benches and sunken valleys amid the rising pools of which the north pool was the highest. Depression main pool 312 feet.

During the afternoon a torrent of lava poured over the north wall of the north pool and flowing along the wall valley of the main pit filled a large part of the northeast sunken area. The north pool had now gained again in height above the main pool; the north pool was 299 feet below the rim, the main pool 312 feet (Pl. 48).

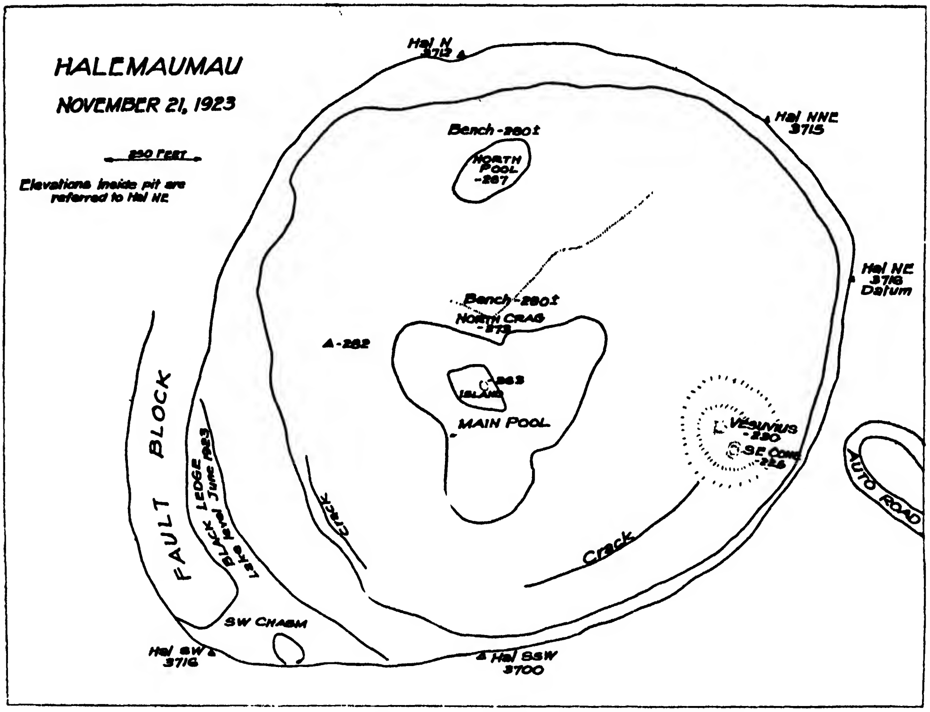

FIGURE 12.—*Halemaumau surveys, November 21, 1923*

Showing a cone replacing the east pool, main and north pools at about the same elevation, and much building up of floors. Depression of main pool 286 feet.

MAP OF NOVEMBER 21, 1923 (FIG. 12)

General rising had occurred so that both north and main pools were about 286 feet below the rim. Two cones had formed at the southeast source about 60 feet high relative to the lakes, the northern one called "Vesuvius" because of its miniature resemblance to that volcano (Pl. 48b). On November 19 at 11:00 a.m. this conelet let off a blast of gas that lasted 5 minutes and might have been heard 2 or 3 miles away; some lava was thrown up 100 feet. By 3:00 p.m. November 21 the two pools had sunk 5 to 8 feet within their cups with weak fountaining, while the southeast cone was puffing and fuming slightly.

SURVEYS OF HALEMAUMAU, 1924

PROFILES OF 1924

The high level reached December 1923 was exceeded by risings in January 1924 followed by the fairly steady decline of the lava to the explosive eruption of May

1924 (Pl. 76e). The oscillations of rising, with outflow down the mountain, which had occurred in 1922 and 1923 reached a climax in 1924, with submarine outflow. This was the end of the 11-year cycle, and this cycle in turn was the end of a 134-year supercycle. The liquid lava that had returned to the bottom of Halemaumau after September 4, 1923, rose steadily until on January 27, 1924, it was within 121 feet of the rim in a pit that had been greatly enlarged by numerous collapses (May 1922 and later). This was the largest lake of lava ever measured by the Observatory. Then it lowered to dormancy February 15–21, 1924, left a collapsed tumble of solidified paste with a glowing hole whose top was about 400 feet below rim, and this drainage led to a demonstration of fracturing at Kapoho. This is on the eastern Puna rift far beyond Chain-of-Craters, 30 miles away near the east point of Hawaii Island. Thus began the explosive eruption chronicled in Parts 2 and 3.

MAP OF JANUARY 7, 1924 (FIG. 13)

This was the lava culmination preceding explosive eruption. A weekly period of great flooding had alternated with remarkable cascading down sinkholes throughout December (*see* Bulletin, Vol. XI, Fig. 16), and on January 4 to 5, 1924, the southeast cone locality was the main sinkhole. The north pool had overflowed into the main pool. The range in height of the lava maxima in January, from 177 feet to 219 feet below the rim, was less than the fluctuation of some single days. Thus on January 18 the lava rose 65 feet in 16 hours. On January 21 the lava lake was 45 acres in extent with no islands visible, and tumultuous fountains convectionally hurled spray 100 feet vertically. Such was the crisis inaugurated by the map of January 7 and illustrated by Plate 48c.

On January 3 the north pool overflowed southeast into the east loch, as it was called. On January 7 both pools were higher, and the north pool was overflowing rapidly in four large streams across the bench. There was outward streaming from a south source, smaller islands in the main pool were drowned, fountaining was at a minimum, and the southeast cone discharged gas through a crack near its base several times during the forenoon.

LAVA INFLOW AFTER STEAM-BLAST ERUPTION, 1924

The first volcanic event following the steam-blast engulfment of May 1924 (*see* Parts 2 and 3) was the inflow of liquid lava through the broken rocks at the bottom of Halemaumau pit July 19–31, 1924. The pit had been left unstable with many small earthquakes and avalanches in June, and walls more than 600 feet below the rim exposed red-hot hard intrusive bodies. A local seismic spasm led to a strong shock June 13 when new cracks were produced in the soil outside the north rim of the larger Kilauea Crater. Observatory seismographs of the northeast rim of Kilauea exhibited tilt to the northeast twice during the 3 weeks preceding lava outbreak.

MAP OF JULY 10, 1924 (PL. 82a)

The condition of Halemaumau bottomed with debris June–July 1924 before the inflow of lava is exhibited by Plate 82a and the lowest profile of the cross section of Plate 83d. The lowest measured point on the bottom July 10, 1924, was 1280 feet below the northeast datum station, but this station at an elevation of 3650 feet above sea level was a very different datum point from the northeast station of 1923

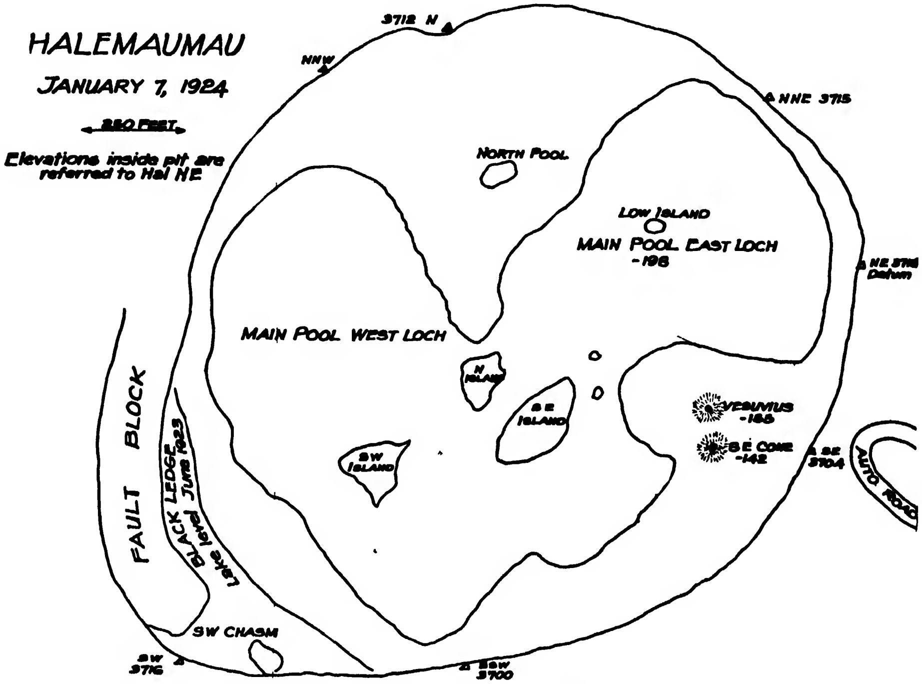

FIGURE 13.—*Halemaumau surveys January 7, 1942*

By Emerson. Showing the condition of high level (Pl. 48 c) 4 months preceding the explosive eruption and the last map before the disappearance of liquid lava February 21. Here the north pool is diminished by its own accumulations on the bench north of the main lake. Main lake greatly enlarged to east and west lochs about 198 feet below datum (northeast station elevation 3716 feet), with three islands. Highest level was to be reached January 21 with main lake 114 feet below rim. After January 27 positive subsidence set in to a tumble of slumped epimagma with depression of its bottom from 375 to 400 feet from February 21 to about April 24 when there was splashing lava in a well about 400 feet below rim. This well was southeast. Sinking of the northeast end in funnel shape occurred April 29–30 to depression 500 feet gradually engulfing the north pool vent in the direction of the main pool east loch. The interesting feature of this final slumping at the northeast is that this is the direction of the Chain-of-Craters rift and the Kapoho supposed outflow under the sea.

(Figs. 7–12) at an elevation of 3716 feet. Hence the broken line marking the datum level of the rim of the pit at the top of Plate 76e, which drops to a lower level in mid-May 1924. In the same way the 1922 diagram shows lowering of the rim. This change of survey stations in 1924 was occasioned by the fact that the engulfment had taken off 700 feet horizontally and radially of the Halemaumau edge when the diameter was enlarged, just as it had taken off 100 feet or more all around in May 1922 with the first enlargement. As the outer ground sloped away from Halemaumau the new rim station was necessarily lower, and the site of the earlier rim station 3716 feet was now a point in the air upward and inward from the new station. Thus it appears that the new bottom if referred to the 1923 datum station represented a depression of 1396 feet. It will be seen by the contours and the profile section that there are crescent fault blocks which slipped down toward the void as well as low-angle talus accumulations, making of the cross section a much flatter funnel than would be imagined by an observer.

SURVEYS OF HALEMAUMAU, 1924–1934

SEQUENCE OF MAPS, 1924 TO FEBRUARY 1929 (PL. 82)

The map of 1926 (Pl. 82 b) is a composite of effects of the lava inflow of July 19, 1924, and avalanches 1924–1926 from the north and west that buried much of the floor. Plates 82 and 83 exhibit the succession of lava fillings to and including 1934, without rehearsing the detail of inflows, duration, landslips, and swellings covered in Part 2. The minutiae of hours, fountainings, and daily journals may be found in the Bulletin and the Volcano Letter. These map plates and the structure section show the totally different habit of the eruptions of Kilauea volcano (Pl. 85, map of southeast Hawaii) after 1924 as compared with what went before (Figs. 7–13; Pls. 77–81). This is shown also in the column diagram (Pl. 74a) exhibiting the maximum elevation achieved by each eruption of new lava within Halemaumau from 1909 to 1935. Where this lava had been free-moving continuously as a fluid from 1909 to May 1924, it became thereafter a succession of sheets solidified from subhorizontal bottom pools through nearly 600 feet of elevation, with progressively thicker layers as the 11-year cycle 1924–1934 progressed.

The outbreaks sometimes resulted from splitting the bottom cake of fill from southwest to northeast along the old fracture of the mountain. Generally, however, the eruption was characterized by fountains along the margin of the next preceding lava accumulations, and the active margins were notably at the west and north. The large west talus was a favorite place of outbreak, its conoid surface extending far up the west-southwest wall, and its large broken fragments of 1924 making a screen for filtration of liquid lava from far below the gravel flat of July 10, 1924. Inspection of the whole series of maps shows that half-cones of lava accumulation at the south or southwest were characteristic of all the eruptions except February 1929 (Pl. 82d) and September 1934; the February 1929 eruption at the northwest margin of the floor of 1928 was merely a short-lived preliminary to the July flood with a southwest source. There was a southwestern cone source in 1924, not shown on the 1926 map, where the western half is buried under talus (Pl. 83 d, cross section). The 1930 cone was at the south, though not against the talus.

All these southwest sources, which even in 1934 took the form of cascades from a concentric crack across the talus high up the southwest wall, are over a vent close to and fed by the rift line marked by the open tunnels of 1919–1920, shown in the high wall of the pit southwest (Pl. 45 b). These tunnels, shown in all the maps 500 feet northwest of the south station (3690 feet elevation) 200 to 400 feet below the rim, mark the outcrop of the dikes that in the Kau Desert flows of 1920 connected with the Halemaumau lava lakes. These dikes extend across the pit to the wall under northeast trig station (3650 feet elevation) and are there over the extension

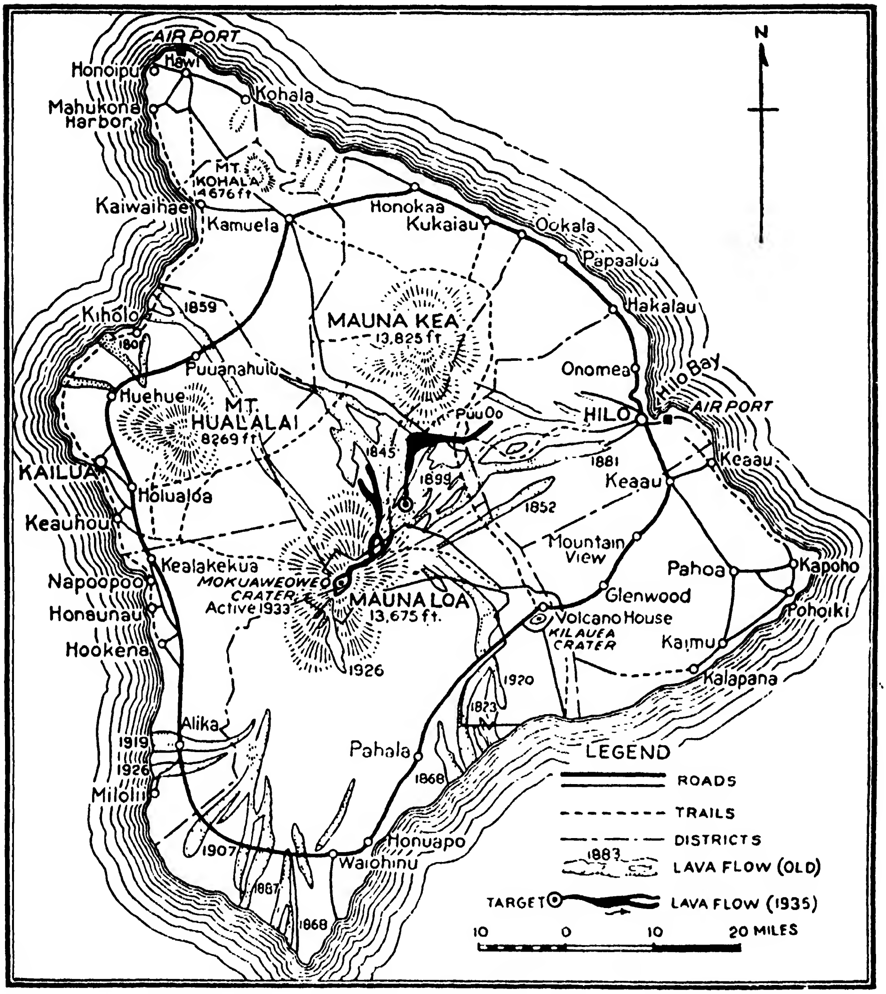

FIGURE 14.—*Map of Hawaii*

Showing approximate position of principal Mauna Loa flows in 1936 and in black the rift flooding from Mauna Loa northeast of November 1935, and farther northeast the Humuula flow making rectangular bend toward Hilo, with front arrested in Puu Oo ranch by Army bombing at locality indicated as Target. 1855 flow lies between 1899 and 1881. 1942 flow is alongside 1852 southeast.

of the deep rift of Kilauea mountain which bends eastward toward the Chain-of-Craters in Puna.

With all the activities whereby Halemaumau was drained in 1922, 1923, and 1924 in the direction of Chain-of-Craters and Kapoho (maps Fig. 14; Pl. 85), there has been no symptom in any eruption of the later series that the return of the lava was concentrated in a cone source northeast. Even 1934 made its great cascades at the west, and even the fountains of February 1929 were at the west. The suggestion is, therefore, as shown by the southwestern cone sources, that the succession of eruptions from 1924 to 1934 derived its lava from the backing up of the deep Kau Desert dike of 1920.

This is of much theoretical interest, because in 1938–1939 (Pl. 86c), when for more than 3 years there had been no outbreak in Halemaumau, an intense seismic spasm as in 1922–1924 developed in the Chain-of-Craters, with disturbance of fault cracks and breakings and humpings of the roadway and the line of pits. This appeared to be an intrusion phenomenon that may well have marked a backing up along the eastern rift of the submarine outflow lava of 1924. In April 1940 lava had not returned to the bottom of Halemaumau, but there were sulphur stains and seismic epicenters at the east side, and there had been large avalanches northeast to suggest a next outbreak on the eastern or Chain-of-Craters side.

SEQUENCE OF MAPS, JULY 1929 TO DECEMBER 1934

In Plate 83 the outstanding feature of the four maps is the increase in size and height of the lava layers added to the bottom of the pit. In February 1929 (Pl. 82d) lava had burst up along a rift in the old floor trending N 63° E about 270 feet out from and parallel to the northwest edge of the floor. The activity continued 36 hours and was voluminous, new lava spread completely over the old floor and extended itself up the talus slope and made a surface with average diameter of 1600 feet covering 40.5 acres. Its mean level was 45 feet above the average surface of 1927–1928 (Pl. 82 c).

The map of July 1929 (Pl. 83a) represents the flood from source fountains through the southwest edge of the old floor close to the center of the 1927 fountaining area, the maximum elevation of the surface and end of inflow being reached 87 hours after 5:00 a.m. July 25, 94 feet above the preceding floor, and 2640 feet above sea level. The first 24 hours produced 44 feet of this, the second day 77 feet, the third day 88 feet, and 13 hours later 94 feet was reached. Withdrawal of lava and shrinkage reduced the elevation of the surface 39 feet so that the final cooled fill had a surface area of 55 acres and average depth of layer 55 feet.

The map of 1930 (Pl. 83 b) represents eruption that broke through the 1929 floor in three fountain groups south of the central region, one building up a cone. The lava spread over the former floor, built a lake surrounded by ramparts, this overflowed on three sides, and after 2 weeks the lake area measured 800 by 500 feet, the cone was 75 feet high and 200 feet in diameter at the base, the entire new bottom area measured 2300 by 1700 feet, and the new mound stood above the 1929 bottom 175 feet at the cone, 100 feet at the lake, and at the north side of the floor about 50 feet. Ending December 7 the inflow occupied 433 hours. The new floor covered 62 acres, its average depth was about 70 feet, its surface elevation above sea level varied from 2650 to 2690 feet, and the stratum of fill contained about 229 million cubic feet of new lava weighing over 15 million tons.

At this time (December 31, 1930) the dimensions of the bottom in the 5½ years from 1924 to 1930 had increased from 1000 by 700 feet to 2200 by 1700 feet, as the funnel filled to a depth of about 350 feet. The volume, exceeding 463 million cubic feet, came in during six eruptions having combined duration of 1133 hours, or 47.2 days of activity, averaging 9.8 million cubic feet per flow-day. The first few hours of any inflow produce the largest volume; rate of inflow varies greatly in different eruptions.

The area of floor 1930 seemed only slightly larger than that of 1929, but the 10-foot bottom contours indicated much greater relief of its dome. It thus made up in height what it lacked in extent; its actual maximum thickness was much greater than that of the inflow of July 1929.

The map of 1931–1932 (Pl. 83c) represents the product of an eruption beginning December 23, 1931, ending January 5, 1932, and occupying 341 hours of actual inflow. This produced a much thicker layer than the inflows preceding it, though its duration was less than 1930 and barely exceeded 1927 (Pl. 83d). Its gas energy and the size of its conduit were greater. Surveys January 5, 1932, when the crust over the lava accumulation was highest, showed the following thicknesses of fill and elevations above sea level:

	Feet	*Elevation Feet*
Location over 1930 conelet filled	73	2793
Southwest bay filled	134	2792
Lake and southwest cone filled	125	2798
Lake SW of center filled	107	2777
West bay filled	113	2773
Southwest cone above 1929 cone	185	2900

The average bottom elevation of 2789 feet was 855 feet below the tourist station southeast and 469 feet above the gravel bottom flat of July 1924. The new bottom measured 2500 by 2000 feet.

The map of 1934 shows the voluminous inpouring at the end of the cycle that had begun in 1924; the finishing crisis of the 11 years for the Hawaiian volcanic system was the Mauna Loa flow November–January 1935-1936, successor to the Mauna Loa crateral eruption of December 1933.

DISCUSSION OF HYDROSTATIC EFFECTS

The gushing inflow to the bottom of Halemaumau September 6, 1934, and ending October 8 (Pl. 83d, with structure sections 1924 to 1934) greatly increased the volume of lava in the bottom of the pit as shown by the structure section. A remarkable feature of the section and the column diagram (Pl. 76) is that volume has increased by no decreasing thicknesses for each eruptive period (combining 1927–1928 and February–July 1929) in disregard of the vastly increasing diameter of funnel. The inverted cone section, if eruptions were volumetrically alike, would lead to expectation of thicker fills at the bottom, but such is not the case. The following are actual elevations at about the center of the pit, and the thicknesses:

Map epoch	*Elevation Feet*	*Thickness Feet*
1934	2881	90
1932	2791	106
1930	2685	85
1929 (all)	2600	59
1927–1928	2541	138
1924 (July)	2403	83
1924 (May)	2320	
Average		93

These thicknesses at the center do not agree with the averages given for each eruption, as they disregard the source heapings. They show survey elevations.

This somewhat uniform rise suggests a hydrostatic control that disregards the volume required. The great increase of 1927–1928 followed high-level outflow 1926 on Mauna Loa, and the increase of 1932 preceded another such Mauna Loa eruption 1933. If Mauna Loa is a reservoir, and Kilauea a siphon gauge, for gas-charged magma slag, we may think of the unknown tidal stress as forcing the main magma secularly upward, to the cycle culmination of strain 1935 under Mauna Loa. The deep column affected the Kau Desert dike leading to Halemaumau as a devious offshoot.

As the two edifices seismically yielded along faults, after the repose of 1925, a consistent average of relief of lava pressure, or magma charge, was maintained:

Inflow	Kilauea	1924 July
Outflow	Mauna Loa	1926 April
Inflow	Kilauea	1927 July
Inflow	Kilauea	1928 January (small)
Inflow	Kilauea	1929 February and July
Inflow	Kilauea	1930 November
Inflow	Kilauea	1931 December
Outflow and Inflow	Mauna Loa	1933 December
Inflow	Kilauea	1934 September
Inflow and Outflow	Mauna Loa	1935 November
Outflow and Inflow	Mauna Loa	1940 April

This magma charge of gas pressure, relieved by lift of fault block or crater plug, and restored by an equation of forces including increased viscosity due to loss of gas heating, may be hydrostatically controlled through the 11-year cycle by rise of hypomagma within the Mauna Loa dome, siphonally but not freely in communication with Kilauea dike fissure.

Mauna Loa shaft is large and high, Kilauea crack is small and low (Fig. 14). Such a paste does not find its level like alcohol, but it controls a pressure. The age-long releasings in relation to weight of edifice mark adjustment to pressure. The reasonable averages of 1.5-year interval for lower and smaller Kilauea, 3.3-years interval for higher and bigger Mauna Loa, during 150 years, with singularly consistent accordance with 11.1-year sunspot cycle (Jaggar, 1938, Pl. 86) make the hypothesis of steady rise attractive. The 1935–1939 repose period is sequent to the cycle 1925–1935.

When this steady rise regardless of volume appears in Halemaumau, notably omitting the Mauna Loa years, it would appear that the controlling column is a stiff substance at a higher level in the larger and more central edifice. As Mauna Loa crater withheld action 1920–1925 while Kilauea violently effervesced and flowed, but Mauna Loa returned to work at the very summit, 1926, regardless of Kilauea's outflow under the ocean 1924, Kilauea's connection must be small and the substance stiff. The free flow is limited to pressure release and effervescence. There is certainly basis for the 11-year and 33-year sudden drops of Halemaumau lava at sunspot minima and for the participation of Mauna Loa flows in Kilauea risings during sunspot increases (Pl. 86). There is a clear supercycle of maximum efflux 1855–1887 for the system, and two explosive depressions that were Kilauea submarine outflows 1790 and 1924 during Mauna Loa minima. There was lengthening of sunspot intervals both backward and forward from the 1855 crisis.

The tidal controls accordant with sunspots are complex and unknown, but that there is rhythm is certain. Such rhythm suggests a uniform magmatic stress and a periodic strain. Joint participation of Mauna Loa with Kilauea in the 1855 climax is evident. Mauna Loa does not show drops, because Mauna Loa crateral lava is not continuously observed; the edifice is too high and inaccessible. It probably grows partly by internal intrusion and submarine outflow, both of which science will some day measure. Volcanology has not yet scratched the surface of this magnificent opportunity. A living volcanic system is always "active".

MAP OF OCTOBER 1934 (PL. 83d)

The events were described in Part 3 and in the Volcano Letter of the months concerned, and also in No. 441. At 2:44 a.m. September 6, 1934, the inner plug of Halemaumau lifted and carried with it a wall slab 300 feet high on the west. Lava boiled up the wall crack west and north (Pls. 56, 57). The cascades west ended at 6 a.m. The more violent northwest fountains ended at 3:30 p.m. At 8 a.m. the pool across the whole pit had 90 acres of surface, was 60 feet deep, and contained 9 million cubic yards of slag. The eruption endured 816 hours.

On September 7 a circular lake 1200 feet in diameter had concentrated at the north. September 9 the whole crust or floor outside the lake slumped 15 feet down and away from the lake saucer solidified around the edges. September 10 the lake measured 1000 by 400 feet, with rampart overflows; September 20 it measured 744 by 390 feet; September 29, 812 by 360 feet with inner spatter cones 20 to 30 feet high. It was now the crest of a slagheap 75 feet above the south edge of the floor. Intrusion had set in at the localized heap and, where on September 9 the slumped crust had been low, marginal flows and swelling had lifted it 40 feet in an elephant's back above the wall valley. By October 8 the shrinkage vertically of lake basin and marginal lift of floor edge had restored the slagheap to a plain. Ten radiating tension cracks centered at the lake. The eruption ended with gas-impelled flings from the conelets in the lake basin. The final elevation of these was about the same as the southwest cone of 1932, the peak of which still persisted (Pl. 83d). The structure section shows the cascades frozen on the wall slab west, and how these free wall slabs or downsunken fault crescents were left from the engulfment of 1924. The final lava lake definitely north-northeast from the center of Halemaumau was in contrast to all the earlier enduring cone sources southwest and leads to a query: Is the next Halemaumau bottom outbreak to be northeast because the northeast Kilauea rift resumed tumescent uplift 1938–1940? The story of this uplift may be read in the Volcano Letter.

PART 5.—HAWAIIAN CRATER HISTORIES

GEOLOGIC HISTORY OF HAWAII

GENERAL STATEMENT

The author has elsewhere (Jaggar, 1920) sketched the geographic history of the Hawaiian ridge and a possible succession for the volcanoes Kohala, Mauna Kea, Kilauea, Hualalai, and Mauna Loa. The relations in age of these volcanoes have been considered by Stearns, Stone, and Wentworth. Bibliographies of the staff of Hawaiian Volcano Observatory have appeared in Bulletin Vol. 4, No. 4 (misprinted III, No. 4), in Volcano Letter Nos. 384, 456; and other relevant bibliographies were compiled by Stearns (1930 p. 36) and Jaggar (1931).

OTHER VOLCANOES AS CRATER CENTERS

In the Volcano Letter have been published items of crater history for the following numbers:

Akutan: No. 352
Aniakchak: No. 375
Bandai-san: No. 301
Batoer: No. 215
Bogoslof: Nos. 275, 322
Boqueron: No. 14
Cascade Mountains: Nos. 363, 376
Costa Rica: Nos. 39, 354, 355
Crater Lake: No. 451
Etna: Nos. 202, 204, 211
Falcon Island: No. 210
Hualalai: Nos. 248–251, 309–310, 347
Izalco: No. 19
Japanese volcanoes in series: No. 323
Kamtchatka: No. 353
Katmai: No. 305
Kilauea: Nos. 243, 290, 319–320, 364, 370, 415–416, 441
Krakatoa: Nos. 196, 230, 234, 306
Lassen: Nos. 199, 266, 304, 306, 334
Llaima and Calbuco: Nos. 284, 314
Matavanu :No. 300
Mauna Loa: Nos. 360, 365, 370, 406–407, 439
Mayon: No. 259
Merapi: No. 387
Montserrat: No. 449
New Zealand volcanoes: Nos. 243, 265, 270
Niuafoou: Nos. 265, 312, 318
Ngauruhoe: No. 216
Nyamlagira: Nos. 434, 458–459
Pelée: Nos. 262, 380
Rabaul: No. 448
Rokatinda: No. 207
Sakurajima: No. 308
St. Paul Island: No. 335
Santa Maria: Nos. 87, 262, 356
Soufriere: No. 359
Tarawera: No. 346
Tarumai: Nos. 276, 317, 342
Tengger: No. 257
Vesuvius: No. 239
White Island: Nos. 66, 206

HALEMAUMAU AS SPECIAL CENTER

For Halemaumau the following special accounts and discussions in the Volcano Letter may be recommended as bearing on crater history:

Ash, deposits at Kilauea: Nos. 17, 125
Avalanches, Halemaumau: Nos. 269, 283
Borings, Kilauea Crater: No. 77
Breathing cones and 1929 activity: No. 263
Bubbling, Kilauea lava: No. 277
Bulk displacement at Kilauea: No. 74
Chain-of-Craters, Kilauea: No. 173
Crack measurement and tilt at Kilauea: No. 446
Cycle, peak of Kilauea: No. 330
Dimensions of Halemaumau: No. 184
Earthquakes, Kilauea 1927: No. 170
Earthquakes, Kilauea 1928: No. 219
Earthquake, Kilauea record of large: No. 457
Engulfment and steam-blasts: No. 451
Eruptive cycles, Hawaiian: Nos. 325–326, 330, 332
Explosion clouds, Kilauea: 1924: No. 37
Explosive eruption, Kilauea 1924: Nos. 328–329
Faulting, Chain-of-Craters: No. 462
Fossil footprints Kilauea: Nos. 273, 357
Furnace, Kilauea as: No. 267
Gas investigation Kilauea: No. 455
Ground movement and periodicity, Kilauea: Nos. 143, 288

Halemaumau eruption 1927: No. 133
Halemaumau eruption 1928: No. 159
Halemaumau eruption February 1929: Nos. 217–218
Halemaumau eruption July 1929: Nos. 240, 271
Halemaumau eruption 1930: Nos. 309, 311
Halemaumau eruption 1931: Nos. 366–367
Halemaumau, map of 1932: Nos. 391, 394
Halemaumau rim crack measurements: No. 393
Halemaumau, sinking of lava: No. 324
Halemaumau statistics 1924–1929: No. 243
Hawaiian expected eruption: No. 209
History Kilauea research: Nos. 381, 384
Isostasy of Hawaii: No. 192
Kilauea cracks, temperatures of: No. 301
Kilauea eruption 1934: Nos. 415–416, 441
Kilauea gases, composition of: No. 295
Kilauea in 1823: No. 450
Kilauea lava flow, 1823: Nos. 18, 81
Kilauea Observatory 1937: No. 454
Lava cascades, Halemaumau: No. 278
Lava varieties, Kilauea: No. 272
Magnetism in Hawaiian basalt: No. 7
Measurements of Kilauea in 1927: No. 130
Microseisms at Kilauea: No. 396
Observatory methods, Kilauea: Nos. 435, 437
Overflow, Halemaumau: No. 280
Pahoehoe and aa lavas, Kilauea: Nos. 281, 294
Pisolites, Kilauea: No. 181
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CRATER HISTORY DISCUSSIONS IN OBSERVATORY BULLETIN

As the Bulletin of the Hawaiian Volcano Observatory 1913–1929 is not indexed, discussions bearing on the subject of crater history are here listed, as many of these are somewhat buried. They are as conclusive now as when they were written, and there is no need to repeat them.

Aleutian Observatory, proposed: Vol. XVI, No. 10, October 1928.
Amphibian Boat for exploration: Vol. XVI, No. 4, April 1928.
Ancient rock pictures, cavern: Vol. IX, No. 8, p. 129, August 1921.
Ash 1790, crag motion, triangulation: Vol. IX, No. 6, p. 100, June 1921.
Avalanche tremors: Vol. XIII, No. 2, February 1925.
Avalanches precede eruption. Vol. XVII, No. 1, January 1929.
Bench magma, luminosity, energy: Vol. IX, No. 3, p. 43, March 1921.
Bench magma, wall veneer, fossil footprints, reheating of wells: Vol. IX, No. 10, p. 155, October 1921.
Bore-holes, temperatures of Kilauea: Vol. XV, No. 3, March 1927.
Bore-holes, thermal gradient of: Vol. X, No. 7, July 1922.
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Borings in crater, preparation: Vol. X, No. 4, April 1922.
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Caverns, streaming, fountains, crag movements, tremor: Vol. IX, No. 9, p. 139, September 1921.
Chain-of-Craters Lava flow, Kilauea: Vol. XI, No. 8, August 1923.
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Energy, bench magma, luminosity: Vol. IX, No. 3, p. 43, March 1921.
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Explosive eruption of Kilauea: Vol. XII, No. 5, May 1924.

Explosive eruption, volume relations of: Vol. XII, No. 12, December 1924.
Explosive fissure, illustrations of 1823: Vol. XII, No. 11, November 1924.
Fossil footprints, reheating of wells, bench magma, wall veneer: Vol. IX, No. 10, p. 155, October 1921.
Fossil footprints, surface oxidation: Vol. IX, No. 7, p. 113, July 1921.
Fountains, crag movements, tremor, caverns, streaming, fountains: Vol. IX, No. 9, p. 139, September 1921.
Fumes, sudden thinning of: Vol. IX, No. 11, p. 173, November 1921.
Gas analysis Sulphur Bank: Vol. X, No. 8, August 1922.
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Mauna Loa southwest rift, exploration: Vol. XI, No. 8, August 1923.
Mauna Loa summit 1920: Vol. VIII, No. 6, p. 76, June 1920.
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Puna craters Kilauea, eruption in: Vol. X, No. 5, May 1922.
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Radial thinning of ash 1924: Vol. XII, No. 7, p. 74, July 1924.
Red hot intrusives revealed: Vol. XII, No. 6, p. 59, June 1924.
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Surface oxidation, fossil footprints: Vol. IX, No. 7, p. 113, July 1921.
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Ten years' work, review of: Vol. X, No. 4, April 1922.
Thurston's lava tube, survey of: Vol. VIII, No. 3, March 1920.
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Tides in Hawaii, levelling, gravity: Vol. XV, No. 6, June 1927.
Tilting, pulsations of: Vol. XII, No. 4, April 1924.
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Uniform heights of rising: Vol. X, No. 12, p. 129, December 1922.
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Viscosity of lava: Vol. XV, No. 1, January 1927.
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Winter rise and summer lowering: July 10, 1913.

MATERIALS FOR CRATER HISTORIES

Perusal of these lists shows that a crater history is not the simple doings of a cup in a cone. It is obviously impossible to repeat here even the crater actions of 20 years. That has been told in all the chapters of this book. It involves the eighteenth and nineteenth century stories, which will be found in Dana, Hitchcock, and Brigham. It involves the entire bibliography of the geology and physical geography of the Hawaiian Islands that will be found in the writings of Stearns and Clark, Stone, Wentworth, Sidney Powers, Palmer, Jaggar, Hitchcock, and others, to mention only the twentieth century. It involves geophysics that includes seismology, magnetism, temperature, gas chemistry, solution, and gravity, all of which have been touched upon in the experiments of the Hawaiian Volcano Observatory and of its visitors. And it includes comparative volcanology, which takes us to the textbooks of Sapper, Mercalli, and Von Wolff, and the volcanologic reviews of Naples, Berlin, Holland, Java, and Japan. A crater is always a part of a faulted geological structure and is always the surface index of magma that is fundamentally intrusive. The word "eruption" meaning external rupture always connotes the end event of irruption, meaning internal rupture or intrusion. In a fire pit like Halemaumau, Vesuvius, Stromboli, or Nyamlagira, irruption may seethe for years at a surface window; it is a precious exhibit of effervescent intrusion open subaerially. The more viscous magmas effervesce and tumesce slowly inside the edifice, seismically. In both the dome breaks, and eruption ensues. In both there is seismical action, not realized by Dana, because it is mostly highly localized and instrumental, even crateral. Most volcanologists do not dwell in craters or on rifts, and very few craters have ever been equipped with sensitive seismographs. Location 15 kilometers away misses most of the shocks. The great earthquakes of a volcanic system have excentric sources.

CYCLES OF KILAUEA AND MAUNA LOA

The diagrams (Pls. 74, 86) visualize measurement of Kilauea and Mauna Loa 22 miles apart with the highest rims of their central sinks respectively 4090 feet and

13,651 feet above mean sea level. The rift crack athwart the craters and far down the mountain flanks is in each case just as active a vent in history as the pit on top. The shield domes are built elongated to the rifts (Fig. 14). In every world volcano, failure to recognize the deeper active rifts has caused misunderstanding of the deeper facts of volcanic systems. There are linear rifts from volcano to volcano in the same system. There are transverse rifts en echelon which have merged to form the linear rift. There are longitudinal cracks along single domes controlled by the ancient breakage of large accumulations above the fundamental rift belt. And there are concentric crackings determined by rhythms of inbreak through the ages at a single domical structure. Each center of radial construction of a dome edifice is influenced in some measure by a tectonic succession of deep cracks.

The sink craters of Kilauea and Mauna Loa are "calderas" with active lava pits or cones inside. The decade 1914–1924 (Pl. 74) is a single cycle of 11.1 years with lava rising in Kilauea until 1919, then sinking and recovering with a series of flank outflows of Kilauea, all within the cycle. Kilauea spurted and lowered with each eruption of Mauna Loa, because the lava in Halemaumau pit was not frozen to the walls, as during the following cycle, but was in some sense fluid and mobile and subject to measurable rise and fall. The outflows from Kilauea 1920–1924 were from the rift belt on both sides of this volcano's summit crater.

These outflows of Kilauea in the Kau Desert 1920, from the summit crater itself 1921, and in the Chain-of-Craters to the east 1922 and 1923 ended with a voluminous rising until January 1924, followed by tremendous lowering and cracking open of the eastern rift belt to the seashore and beyond. At Kilauea Crater steam-blast explosion accompanied engulfment as Halemaumau pit caved in and enlarged. The volume of matter ejected as $\frac{1}{250}$ of the volumetric enlargement of the lava pit. The conclusion was justified and enforced by seismometry that the lava escaped seaward, engulfment was the principal crater maker, and ground water entered the subcrateral void.

No explosive eruption of Kilauea Crater prior to this one had occurred since about 1790. Increasing volumes of lava were pumped out of the Hawaiian volcanic system from 1790 to 1855, and decreasing volumes accompanied by notable Halemaumau collapses gave occupation to the system during the 67 years from 1856 to 1924 (Pl. 86). The 134-year period showed the Hawaiian volcanoes executing a greater culmination or supercycle of maximum volume in 1855 in a series of 11-year peaks of lava rising, each similar to the decade 1913–1924.

Like the last half of our 1913–1924 decade, so our 134-year greater cycle was punctuated during its receding years by a series of cataclysmal sudden lowerings for Kilauea in 1855, 1891, and 1924 while Mauna Loa outflows notably dwindled in duration after the voluminous floods of 1855, 1859, and the crater fillings of 1872–1877. Though the 1919 decade was exceptional in bringing the supercycle to an explosive end, its other features of gradual rising, spasmodic lowering, and Mauna Loa coincidences are indicative of an 11-year habit worth examining for rhythm.

The seasonal controls of such rhythm are suggested by the special charts of Kilauea rising and seismic frequency of 1914–1916 (Pl. 75a). The Kilauea risings were progressively greater at intervals of 9 months, the first and third accompanied by Mauna Loa outbreaks, the second by a Mauna Loa swarm of earthquakes. The two

Mauna Loa eruptions culminated on solstice, the seismic swarm on equinox. The seismic frequency chart for this period showed corresponding peaks, each beginning with epicenters located seismometrically at Mauna Loa distances from station, and ending with earthquake sources at Kilauea distances. The time of lower lava level and lower earthquake frequency coincided with occurrence of strongest shocks, as though these were measurably stimulated by lava confinement.

The symmetry of these measurements implies tidal release of a uniform force. E. W. Brown's (1925) investigation of Jaggar's data for the lava-tide measurement of Halemaumau suggests a luni-solar release. Perret and Wood have worked on seismo-volcanic curves in the semiannual group and on astronomic controls and have found correspondences for equinox and solstice (Perret, 1908; Wood, 1917b). Doctor Douglass (Jaggar, 1938, p. 26) has examined our curves in comparison with his "tree growth and climatic cycles" (1933) and suspects the presence of the half-sunspot cycles.

KILAUEA AND MAUNA LOA IN THE NINETEENTH CENTURY

Plate 86 groups the known facts, and there follows here a grouping that tabulates them for Mauna Loa and Kilauea during 150 years, showing such measurements as have been reported. The data are from the standard books and from the Hawaiian Volcano Observatory after 1912. The most valuable quantitative data are from Hitchcock's table (Hitchcock, 1911, p. 272) now plotted graphically. The duration in weeks of Mauna Loa eruptions was studied by E. G. Wingate and is expressed as columns from an unpublished chart among the Observatory records. The following is the list of events, and Plate 86 is their graphical expression, for Mauna Loa, Hualalai, and Kilauea, for the repose periods (R), for the sunspot minima (S−), and the sunspot maxima (S+). KF means Kilauea outflow. The elevations of the highest stand and the lowest stand of the lava of Kilauea in feet above sea level for the climax years indicated are drawn from Hitchcock's table. The dated years for Mauna Loa are flank outflows, the other columns being crater fillings, of which the most enduring was the continuous activity of 1½ years in the summit crater of Mauna Loa in the early 1870's. After 1840 Kilauea lowering means change of Halemaumau internal contours (Pl. 86). After 1892 when 2 years of lowering appear for Kilauea within 11-year cycles, only the last is used for Plate 86, though the table gives the total range of depression. (The separate years are given in Jaggar, 1938; the "Fig. 2" there is misprinted "METERS" for feet.) After the 1924 end of the explosive supercycle there is no cyclical lowering except floor shrinkage; for 1934 the range is given from highest cascades to lowest floor.

HAWAIIAN ACTIVITIES, 1788–1935

GENERAL STATEMENT

The volcanic activities for the period 1788–1935 are summarized in Table 2. The only data for comparative volumes of lava eruptions, for flank outflows, or

Table 2.—*Hawaiian activities, 1788–1935*

1788	Kilauea lava-flow. No records.
1790	Estimated **Kilauea lowering** from 3500-foot contour down to 2200-foot (above sea level), explosive.
1793	Kilauea lava flow. No records.
1794–1799	Probably quiet period, Vancouver's report. No records.
1800–1805	Two lava flows from Hualalai. No records. Molokini west of Haleakala reported smoking. **Kilauea lowering** from 2800-foot contour down to 2500-foot contour, probably 1800 A.D.
1806–1810	Unrecorded. **Kilauea lowering** probable year 1810. Estimated 3000-foot contour down to 2800-foot.
1811–1823	Kilauea floor built up. No records. Large lava eruption to sea SW, explosive cracks. **Kilauea lowering** year 1823, 3180-foot contour down to 2457-foot (Hitchcock).
1824	Probably quiet. No records.
1825–1832	Lava culminations Kilauea and Mauna Loa. **Kilauea lowering** year 1832, 3365-foot contour down to 2937-foot (Hitchcock).
1833–1834	Probably quiet.
1835–1843	Lava culminations Kilauea 1840, Mauna Loa 1843, **Kilauea lowering** year 1840, 3430-foot contour down to 3127-foot (Hitchcock).
1843–1847	Quiet.
1848–1855	Lava culminations at maximum. **Kilauea lowering** year 1855, 3730-foot contour down to 2700-foot (Weld, Hitchcock).
1856–1858	Quiet.
1859–1868	Lava culminations Mauna Loa (3), Kilauea overflows. **Kilauea lowering** year 1868, 3480-foot contour down to 2957-foot (Hitchcock); great earthquake.
1869	Quiet.
1870–1879	Lava culminations Mauna Loa 1877, Kilauea 1879. **Kilauea lowering** year 1879, 3620-foot contour down to 3320-foot (Hitchcock).
1879	Quiet after lowering.
1880–1891	Lava culminations Mauna Loa (2), Kilauea. **Kilauea lowering** year 1891, 3745-foot contour down to 3055-foot (Hitchcock).
1891–92	Quiet.
1892–1902	Lava culminations Mauna Loa (3), Kilauea rise. **Kilauea lowering** years 1894, 1902; 3678-foot contour down to 3240-foot (Hitchcock).
1902–03	Quiet.
1903–1913	Lava culminations Mauna Loa (2), Kilauea. **Kilauea lowering** years 1908, 1913; 3583-foot contour down to 3075-foot (Hitchcock-Jaggar).
1913–14	Quiet.
1914–24	Lava culminations Mauna Loa (3), Kilauea overflow. **Kilauea lowering** years 1919, 1924; 3740-foot contour down to 2350-foot (Jaggar).
1925	Quiet.
1926–1935	Lava culminations Mauna Loa (3), Kilauea (7). **Kilauea range** year 1934, 3200-foot contour down to 2900-foot (Jaggar).

crateral overflows are flow days, or number of days of average flowing. These came up to a maximum about 1855 as follows:

1790–1820, very few, but unrecorded
1820–1830, about 7 (1823)
1832–1843, 132.
1851–1855, 411.
1859–1868, 307.
1870–1877, 207.
1880–1887, 247.
1892–1899, 37.
1903–1907, 28.
1914–1919, 71.

COMMENTS ON THE DATA OF PLATE 86

There is paucity of data for 1790 and 30 years thereafter, represented by an estimated curve of broken lines. A broken line has been inserted from 1934 to 1946, based on the resemblance of the 1935 Mauna Loa eruption to that of 1843 in location and volume, and the supposition that the culmination of the next 11-year cycle might resemble 1852–1855. There is numerical basis of measurement for the depths of the lava depressions in Halemaumau pit for all except 1790 and the quarter century following. As 1790 was a bigger explosion and engulfment than 1924, its limit of crater bottom is set at 2200 feet elevation, 150 feet lower than the bottom of 1924. The pit rim of the nineteenth century averaged around 3500 feet elevation, which is the figure set for height of pit rim before the 1790 collapse. This pit rim during the century ending 1919 was built up to something exceeding 3700 feet elevation. The evidence of the early missionaries and the measurements by officers of the ship BLONDE in 1825 indicate that construction vertically of 800 or 1000 feet of Kilauea Crater floor by inflow of lava must have occurred during the 30 years that followed the 1790 downbreak, in order to create a floor, the remnant being the black ledge left by the collapse of 1823.

The Kilauea curve is based on the critical years of what Dana, W. L. Green, and Hitchcock called eruptions. By "eruption" is meant a crateral breakdown. It is likely to be preceded by strong effervescent crateral fountaining and overflow and by Mauna Loa flank outflow. All workers have recognized the probability of an elastic limit occasioning these breakdowns and of preceding tumefaction, followed by shrinkage. The recognition of a repose period following collapse as the division index for cycles was well known to Mercalli, who at Vesuvius spoke of "sprofondamento", a deepening, as the index of eruption. The interval between repose periods measures cycles.

Crateral downbreak at Kilauea in 1823, 1840, and 1868 was accompanied by Kilauea outflow from the rift in the mountain flank. The collapse of 1832 was accompanied by outflow in the adjacent deeper Kilauea Iki, so that this is also considered a Kilauea flow (KF). The year 1877 produced a welling up of lava in the adjacent Keanakakoi Crater, precedent to the 1879 collapse. The years 1920, 1922, and 1923 showed visible flank outflows on the Kilauea rift, and the writer has reason for the certainty that submarine Kilauea flow undermined the pit in 1924. All this is explanatory of "KF" in the diagram. It is unthinkable that the great downbreaks of 1790, 1855, and 1891 had no flank outflow, when we consider that the rift belts extend out under the ocean to depths of 2000 to 3000 fathoms; so these downplunges also might be labeled "KF".

SEQUENCE OF EVENTS IN PLATE 86

The emergent facts of the Kilauea curve are a general rising from 1790 to 1855, a high level from 1855 to 1891, ended by decline and collapse to 1924. Mauna Loa (quite unrecorded 1790 to 1832) showed in its crater past the middle of the century a building up of the bottom, marked by continuous action at the apex of its curve between 1871 and 1877. Otherwise the duration of its outflows which were scattered at intervals of 1 to 12 years reached a maximum in 1855 and declined rather steadily thereafter. The year 1855 was critical as combining for both volcanoes the evidence of maximum lava pressure, and the two curves are sympathetic just as they are for 1913–1924 (Pl. 74). If we consider volcanism under Hawaii as magma pressing upward and released by yielding of the edifice, the Hawaiian ridge yielded to magmatic tumescence from 1840 to 1874, with a breakage of Mauna Loa that made a sequence of the most voluminous surface floods of history, 1851–1859, and after 1855 made an unlocated submarine flood of lava from Kilauea.

When these great flows congealed, including Kilauea 1840, the splitting effect of rising rift lava spread to the more brittle and cooled southwestern extensions of the separate rift belts of Kilauea and Mauna Loa making there the terrific earthquakes of 1868. This released southern outflows of Mauna Loa and initiated alternation of north and south outflows during the remainder of the century. Kilauea by habit alternated between southwest and northeast flanks. The 1868 breakage accompanied high levels of both Mauna Loa and Kilauea curves long past the middle of the century. The very high pressure of the 1870's that built up the floor of the Mauna Loa summit crater started exhaustion in the larger unit that controls the supercycles of 134 years; weight had been added to by lava extrusion, and the release of surface land flows declined in duration and volume from 1881 to 1926.

A sequence of southwestern flows of Mauna Loa with outflow vents progressively higher gradually developed in the years 1868, 1887, 1907, 1916, 1919, and 1926. leading to an eruption wholly in the summit crater in 1933. It seems that there was a similar climb of progressively higher vents along the northeast rift of the mountain in the years 1843, 1852, 1855, 1881, and 1899, leading to a summit crater eruption in 1903, when the splitting of the rift crossed the summit and led to the exclusively southwestern eruptions of the first quarter of the twentieth century. This process of outflow vents migrating up the mountain led to logical forecast that the northeast rift would again break open after the summit eruption of 1933, and this happened in the big flow of 1935 on almost the identical crack that had given vent in 1843 to the first northern flow of the nineteenth century. There is historical reason to think that the 1832 flow, preceding 1843, was south of the summit crater just as was the 1926 outflow as precursor of 1935. A succession of southwestern Mauna Loa flows probably occurred at the beginning of the nineteenth century, of which we possess no record. Mauna Loa was remote from the natives, hence the question marks in the diagram. However, this analogy between 1935 and 1843 makes very serious the menace of the next 20 years for the city of Hilo. The United States engineers have surveyed for diversion channels against lava flow, to protect Hilo harbor, which is an extension of the valley between Mauna Kea and Mauna Loa, where scores of lava flows have poured down in the geological past.

In 1940 a new summit eruption of Mauna Loa corresponded, as compared with 1935, to the eruption in Mokuaweoweo of 1849, following 1843. An extraordinary feature in common between 1849 (Coan, 1851) and 1940 is absence of earthquakes. The long sequence of voluminous outflows 1851–1859 following 1849 was notably not greatly seismic, although in 1855 both Kilauea and Mauna Loa were involved, and Kilauea lava subsided. The great earthquakes of 1868 came afterward. Such sequence was repeated with Mauna Loa voluminously active at the summit and north, between 1872 and 1881; the earthquakes of 1887 came afterward. In both cases the seismic spasms accompanied the crossing of the mountain, by the outbreak mechanism, to southern vents.

When absence of earthquakes is notable, as in 1940, although seismographs were set up and ready, the significance may be that the magma in cracks is expansive, abundant, and high. It is worthy of note that 1849, 1851, and 1852 did not deplete Mauna Loa of lava supply; 1855 reservoirs were all ready for a prolonged Hilo flow of 60 weeks, and 1859 for 40 weeks more.

Volume depletion does not determine succeeding interval unless fracture limit of edifice is taken into account. The values for fracture limit were low in the 1850's and high in 1868. The supply of eruptive pressure or magma potential appeared to be controlled only by the resistance. Rhythm of cycle is a matter of average resistance in the system. Magmatic expansion may build up to weaken resistance over a large area as in 1855, to expel large volumes, when tension in the edifice is maintained by dike fillings. The seismic release at low level hydrostatically in 1868, with a series of big earthquakes, restored gravitative mountain pressure, narrowed the dikes, and temporarily checked extrusive flooding.

There are imbricating fault blocks against Mauna Loa southeast, with fault dip in that direction at high angles. These are repeated up to the summit, are curved in plan northeast-southwest, and Kilauea is one step in the series. Some lava risings may weaken their pressure against the mountain, but downslip thereafter restores it.

CORRELATION OF CYCLES WITH SUNSPOTS

Just as the curve of volcanism for Hawaii in Plate 86 shows low values at the beginning of the nineteenth century, rising values in the first half of the century, culmination about 1855, and decrease of height of lava thereafter, so it is striking that the mean numbers of sunspot eruptions (Stetson, 1934, p. 147) show low values from 1790 to 1820 and lengthening of the 11-year cycles; the values increase from 1820 to 1830, reach very high figures from 1830 to 1880, and decline from 1880 to 1920.

There are five extreme low points of the Kilauea curve—1790, 1823, 1855, 1891, and 1924. These were the greater collapses of Kilauea Crater, and the 1823 event was accompanied by some steam-blast eruption along its rift near the ocean, possibly a hangover from 1790. The curve resolves itself into four divisions separated by big depressions, and each division tends to be broken up by two principal minor depressions or eruptions making intervals of 8 to 15 years. The five great crises are almost exactly 33 years apart; treated as calendar years the intervals come out respectively 33, 32, 36, and 33 years. The mean is 33.5 years, which divided by 3 makes the mean of the minor cycles 11.16 years. This checks with the well-known sunspot cycle and matches the cycle 1913–1924 exhibited in Plate 74. The identity of this with a sunspot cycle applies even to dates, for the beginning of the repose periods in 1913 and 1924 and 1935 occurred exactly on the sunspot minima as shown on Plate 86. The other sunspot minima show general correspondence with Kilauea repose periods (R), with S— lagging behind R prior to 1855 and R lagging behind S— until 1924. The true repose epoch usually followed R, which is entered on the chart as the time of lava collapse.

Sunspot maxima, shown by S+ across the upper part of the Kilauea curve, invariably occur at times of rising lava when both Kilauea and Mauna Loa were engaged in an 11-year effort of recovery. To discover the relation of Mauna Loa outflows to the Kilauea 11-year cycles, vertical dotted lines are drawn to the upper columnar diagram. Usually, within the Kilauea cycle, Mauna Loa crater eruptions occur in the first part of the period, and the dated outflows come toward or at the end, as though the tumefying effort of the cycle finally ruptured the rift belts, just as in our type cycle of 1913–1924.

Review of the nineteenth century develops the importance of periodic collapse, alternating with 11-year accumulations of inflow and outflow. Both Kilauea and Mauna Loa have co-operated, but Kilauea has been better measured. Its recessions show four 33-year greater collapses. Measured volumes of output from both Kilauea and Mauna Loa rose to a maximum in the middle of a 134-year period, then declined. Sunspot numbers rose and declined in the same period. The collapse times accorded with 12 sunspot minima. The larger 134-year supercycle begins and ends with a major breakdown of Kilauea accompanied by steam-blast eruption. As a whole the century of scientific observation left both craters more filled than before by a few cubic kilometers.

THEORETICAL POSSIBILITIES CONCERNING SUNSPOTS

It is well known that the gigantic vortices around eruptive sunspots in the high-temperature gases of the surface of the sun develop magnetic fields and that excessive sunspot activity accords with magnetic storms on the earth and affects the electrical phenomena of the atmosphere whereon radio transmission is dependent. In the correspondence between the Kilauea curve and the sunspot minima the detail of irregularity or departure from the mean in sunspot interval and eruption interval was almost perfect in correlation for 1823, 1832, 1840, and 1855. These again coincide in 1913, 1924, and 1935. That the irregularities should produce coincidence suggests an actual stress somehow effected in the magma or the edifice, by the prolonged increase in numbers of sunspot eruptions, and brought to a close, rather suddenly, with the arrival of a sunspot minimum. As the entire earth is capable of being swallowed up in a single sunspot vortex, the sun and not the earth must be the source of the energy, and if there is a cyclical response in magma the magma from centrosphere outward must be solar matter actuated as an electro-magnetic engine by some sympathetic response (*see* Part 6, Hypomagma, last paragraph p. 393) independent of low-temperature ferromagnetism. Diamagnetic control of the core fluid is a possibility, emergent by the ignisepta.

We know by Chevallier's (1925) tests on Etna that mass polarity might arrange the crystals of iron oxide in basaltic lava flows, in accordance with earth's local and temporary declination for the time of congelation. There are great differences of local declination in Hawaii, all Hawaiian lava is magnetic, and J. W. Green (1914) proved that a handful of Pele's hair or filamentous lava, though wholly glassy, will deflect a magnetometer needle. The sun achieves magnetic fields at very high temperatures in vapors of iron, calcium, and hydrogen. We are ignorant of the localized magnetic susceptibility of these and other elements in thermoelectric earthcrust conditions, but they are ingredients of basaltic magma. The Hawaiian differentiation of the much-stirred aa or sprouting lava (aphrolith) and the glassy-topped pahoehoe or skin lava (dermolith) centers around oxidation of the 10 or 12 per cent of iron to many billions of crystals of the magnetic oxide and some sphene. The surface of the sprouting lava is stimulated to crystallize these oxides by gas stirring, along with the feldspar, augite, and olivine. The surface of the vitreous lava forms a skin, when glass separates out on top, and the crystallizing part of the slag is confined by it. Gas is retained in solution by the intricate phenomena of convection, pressure, bubbles, crystallization, heat generation, density, and viscosity, and we know nothing of the possibilities of shock or motion in lava while it is intrusive. Vortical motion may maintain magnetic fields in the high-temperature substance of the inner earth, quite apart from the magnetism supposed to be absent because of high temperature. Green ran magnetometer observations at the edge of Halemaumau in 1913, with lava boiling in the pit, and could detect no response. Nagaoka and Ikebe (1937) have discovered response to volcanic rumbling at Asama volcano, in a magnetograph giving the value of the time rate of variation of magnetic disturbances. They attribute this to changes in magnetic attractiveness for liquid lava underground as it congeals or as it melts. In the one case the crystallization of magnetic oxide of iron would increase its ferromagnetic susceptibility; in the other sudden liquefaction by the melting of minerals through gas heating would decrease the magnetic attraction of the lava because of its increasing temperature, and in either case the magnetograph would show a change, significant of the change of state of the underground magma precedent to some volcanic happening dependent on liquefaction. It hardly seems possible that the correlation with sunspots exhibited by Plate 86 can be fortuitous, but on the other hand it is difficult to imagine a sudden magnetic field by crystallization. Possibly the correlation is not concerned with magnetism but is some radiation or gravitation phenomenon. If it concerns ferromagnetism, the experiments of Chevallier (1925), J. W. Green (1914), and Nagaoka and Ikebe (1937) are worth consideration, with a view to inquiry concerning the intramagmatic motion of large numbers of magnetic microlites. If it concerns rather electrical phenomena in some way related to the hydrogen-carbon-helium sequence (Bethe 1939), then a solar control of ionized atoms inside the earth is evidenced at Kilauea, and we are a step nearer to proof that volcanic lava is very profound.

SUMMIT AMPHITHEATERS

The characteristic feature of both Mauna Loa and Kilauea craters which stands out in studying the map of Hawaii Island (Fig. 14) is that each is at the bend in plan of a rift that traverses the dome in the direction of its greatest length. The two rifts are approximately 15 to 20 miles apart and as structural parts of the island are subparallel. Thus the southeast flank of Mauna Loa is broken into fault steps, which are parallel to a crack extending southwest from Mokuaweoweo, passing through that crater, and then extending east-northeast from it. In like manner a crack extends southwest from Kilauea Crater (Pl. 84), passes through the crater, and extends east-northeast from it to the flow of 1840 at Nanawale. One southwest crack from Kilauea probably passes through Wood Valley, Mohokea sink, and the source of the 1868 flow, all on the south flank of Mauna Loa, because of the alignment of these features and because of some events connecting Kilauea with Mauna Loa which excited discussion in 1868. The evidence of step faults, makers of located earthquakes, along the southeast shore of Hawaii is well marked at the Puna and Kau cliffs above the sea south of Kilauea; these show bends and breaks strikingly accordant (Pl. 85) with those of the cracks of Kau Desert, Kilauea Crater, and Chain-of-Craters to the east. Depth of Hawaiian earthquakes has been measured by Jones (1934; 1935a; b; c).

Critical study of activity at the lava domes which have been repeatedly formed in miniature, such as Mauna Iki in the Kau Desert in the spring months of 1920, has shown that basaltic lava domes tend to break down at amphitheaters in their own flank, whence aa lava drains out as a paste from under such a collapsed area. This was reviewed in detail in 1920 (Bulletin, January, p. 3) when it was shown through several months that every time Mauna Iki piled up to a certain height the shield became unstable, and the confined paste flowed out so as to break down the flank.

This process appears to be of importance in volcanism for the physiographic form and structure of cones. It is illustrated on the island Hawaii by Kilauea, Wood Valley, Mohokea, Mokuoweoweo, the Puu Waawaa embayment, and the Waipio embayment; on Maui by the Haleakala breakage; and on Molokai and Lanai by the breakdown of half of each of those islands. Stearns considers the end history of these valleys as atmospheric erosion carving. That this rupture is a general feature of volcanism, however, is illustrated by such crater-fault valleys, with landslip hillocks, as have been much discussed in Java (Galounggoung, Volcano Letter No. 286). It is evident that this engulfment of the top or the flank of a volcanic mountain may be accompanied by steam-blast eruption as at Pavlof, Bandaisan, or Kilauea, and the undermining by outflow of lava may be through a rift under the sea, through a rift above the sea, by breakdown of a sector of the mountain, or by gushing overflow of the crater sink itself. The writer strongly suspects the Rivière Blanche of Mount Pelée of being a sector break. Kilauea Crater by way of its inner pit Halemaumau and its flank rift fractures may be said to have illustrated all these processes in some measure in the twentieth century. Both the north and south flanks of Mauna Loa at Humuula and Kahuku lands may be thought of as in process of breaking down, undermined by outflow. Hualalai has done so in the Puu Waawaa embayment, and its outflows of the historic period are accompanying the downslumping of that embayment. The embayment extends from Huehue to Puu Anahulu. The hydrostatics of changing viscosity will bear investigation.

By this doctrine it may be asked what part do the multiple cones of cinder play in the old age of such volcanoes (Pl. 72), Mauna Kea being the type? The multiple cones of Galapagos duplicate Mauna Kea, and Hualalai is an early stage. These are magmatic eruptions where the cinder is a pumice and stiff outflow is an accompaniment.

The deep structure of Mauna Kea will bear much more volcanologic investigation (Wentworth, 1937; 1938). Study of the contour map shows a summit dome crowned by a circle of cones, itself with annular plateau at 9000 to 10,000 feet, surmounting a steeper cone slope that grades off flatter downward. This outer catenary profile might have been projected upward into a Fujiyama, if the conclusion of activity had been central, phreatic, and andesitic. It seems more likely that the shield phase became fractured and the basalt somewhat trachytoid and pasty. The result was many cones, short viscous flows, prolonged gas action, almond bombs, and fine cinder that made deep banks of dust to leeward. The summit plateau is a trace of the border of the sink, filled up and overridden by the cone type of activity, and Mauna Loa has just such a fault-bordered summit plateau (Volcano Letter No. 360). Localized phreatic explosion probably played its part. Phreatic steam blasts carrying dust into rain clouds are definitely proved where pisolites (fossil mud rains) can be found.

KILAUEA CRATER AND MOKUAWEOWEO

Dana (1891, p. 149, 229) discussed the mechanism of creation of Hawaiian craters, with recognition of elongation due to rifts, of pit formation occasioned by downplunge and outflow, and of ascensive forces. He attributed vesiculation vapor to ground water and considered earthquake accompaniments of eruption as exceptional. This was then reasonable, as gases had not been collected and seismographs had not been set up. Dana specifically denied the presence of carbon dioxide, and the conception of essential magmatic gases in solution, as ingredients of basalt, came after his time. He sharply separated fountaining from the ascensive force, the latter deep, the former superficial. The notion of a permanent upward magmatic stress of glass with gas in solution, release of pressure by localized yielding, and temperature increasing with chemical change on vesiculation is theory of the twentieth century (Rittmann, 1933).

Dana compressed his vision in one paragraph as follows (Dana, 1891, p. 234):

> "A mountain having within it two great regions of liquid lava (Mokuaweoweo and Kilauea) thousands of feet in height, ten thousand feet or more in diameter, and each at a temperature above 2000° F., and with subterranean waters abundant, at least through the lower two-thirds of the altitude, is well fitted for the production of eruptive crises. It is remarkable that the eruptions of 1868 and 1887 are the only ones seismically occasioned, or attended, in the past sixty-five years; and further, that in these eruptions, although among the most violent on record, the craters were wholly free from explosive action."

To paraphrase this in terms of 1940 the writer would word it:

> A mountain having within it scores of dikes of compressed gas-charged basaltic glass pressing upward, confined by weights of accumulation, cyclically subject to tidal stress, and with gas-tight and water-tight boundaries: the mountain height trivial in comparison with the depth of the dikes. The gases in solution are dominantly CO_2 with H_2. Explosive eruption is a surficial geyser phenomenon related to magmatic lowering. All eruptions and irruptions are seismically attended. Eruptive or irruptive crises are not a function of a crater or a mountain, but of a cracked and yielding earth

mantle. Craters and volcanoes are remnant extrusive expressions of the fundamental magmatic process, intrusion. The products of volcanism are gaseous, liquid, and solid additions to the gaseous, liquid, and solid mantles, and from centrosphere outward the solar matter of volcanism is synthesizing from subatomic to molecular. Volcanism conceived as the heating or melting of rock masses would be a superficial inversion of the fundamental process. The unknown feature is the pressure-solution-temperature condition of gas in glass. If intrusion is worldwide, profound and chemically exothermic, low temperatures below the boiling point of carbon are unlikely in the earth core. (See Gutenberg, 1939.)

The rock mantle is in balanced stress, distributively strained in cycles, the volcanic balance necessarily mostly submarine because submarine mantle makes most of the earth surface. The distributive yielding to stress is mostly submarine, intramantle irruption, sometimes relieved by extramantle eruption. The magmatic breaking forth or eruption or "eruptive crisis" of Dana at subaerial craters and cracks is the minor expression at shore lines, continental rifts, and on islands of the major process which is submarine. The magmatic transition from olivine basalt sea bottom to granitoid continent is a transition from substratum glass to assimilated acid glass, from heavier to lighter intrusive matter, from primitive mantle to contaminated mantle of erosional siliceous concentrates. The unknown and unexplored feature is the actual condition of submarine volcanism, whether eruptive or irruptive.

The longer diameters of Kilauea Crater and Mokuaweoweo do not exhibit island structure. The linear mapped fault-step structure exhibits the *raison d'être* of the craters. Crateral centers of outbreak are nothing more than sunken corners of fault blocks. They are generally sector corners, not intersections. Mokuaweoweo trails off into end platforms and pits because the bend of the rift is small; Kilauea leads into Kilauea Iki at right angles because the sector that breaks the dome so bends toward the Chain-of-Craters. Both Mokuaweoweo and Kilauea are over the widest part of fractures, which widest part trails off to narrower parts by way of pits and cones. The cone is an expression of construction over a crack opening. The pit is an expression of collapse of such construction by downplunge of lava, because the rift gaped open for lava drainage under or near the sea. The volcano rifts are no less there, because unseen by geologists. Enough have been seen above the sea, as in 1823, 1840, and 1924 for Kilauea, to point toward big lava floods under the ocean, on an enormous volcano slope never explored. If rift rupture is aided by hydrostatic pressure, the higher Mauna Loa, with many more subaerial outflows, should be making more unknown submarine outflows than Kilauea.

If many of these submarine irruptions are intrusive sills and laccoliths in deep sediment, then global geology is at a standstill until the facts are discovered by explosive trenching, drilling, and sea-bottom observatories of geophysics. Sea-bottom rock collecting is available to pure science properly endowed, with the aid of engineering inventiveness. Geology will collect specimens of the deep igneous rock under oceanic sediment. When this has been done, there will follow topographic mapping, thermal gradients, chemistry, gravity, magnetism, seismology, and volcanology of the sea bottom, now exciting much interest. Geology today is mostly epeirology, the science of continents, but a splendid beginning is being made in ocean-bottom mapping. Ocean-bottom craters are worthy objects for sonic sounding and dredging.

REVIEW OF CRATER HISTORIES IN HAWAII

Reviewing the structural development of the Hawaiian volcano system a quarter century of unbiased measurement reveals construction of the great slag-heap mountains by both internal tumefaction and extrusion along rifts. The construction is by gas heating and gushing of silica-iron foam through 11.1 years. This is followed by sharp collapse terminating the period. The collapses of minor phase occur throughout the cycle and correspond to alternate, mutual exchanges between craters large and small. Lava lowering is just as frequent as lava rising, and generally more rapid. Seismic indication goes with both movements. Gas collection has shown that the volatile constituents are carbon dioxide, hydrogen, and nitrogen, with minor amounts of carbon monoxide, sulphur, and sulphur dioxide, but that sulphur, water vapor, and chlorine are largely due to crater concentrates by fuming, surface contamination, and surface reactions, wherein the water-gas reaction is the most prominent (Jaggar, 1940). Tests by plotting successive surveys at craters have shown sympathy between Mauna Loa and Kilauea, seasonal rhythms, and definite tidal effects. The sympathy is not hydrodynamic; it is hot, gas-foaming release. Temperature measurement has shown that liquid lava in a pit becomes hotter from below upward (Jaggar, 1917c), and hotter with increased effervescence of gas (Day and Shepherd, 1913, p. 601). Soundings in lava have shown hotter glassy pools, wells, and streams within cooler but mobile crystalline paste; extrusive basaltic lava is hence duplex (Jaggar, 1917d; 1920). This duplicity has long been labeled by Polynesians as aa and pahoehoe, and distinguished by Icelanders, Mascarenes, and Italians; it is the most conspicuous and amazing contrast in the entire volcanic landscape, yet its profound significance has been almost ignored by science. All facts point to continuity of intrusive pressure of magma initially vitreous, triggered by tidal controls and the yielding of the edifice.

What has been suggested above for experimental geology—the hydrodynamic investigation of changing viscosity and its pressure effects—is an illustration of what led the author in 1911 to abandon laboratory experiments for the field. It seemed to him that pure physics and chemistry helps geology less than experimental engineering. Experimental engineering in turn requires specific data. Geology deals with complex edifices and complex materials, which are accessible, and in this it has great advantage over astronomy. But geology like astronomy must live with the gross bulk of materials acting on the edifices and study action, not matter. In the case of epimagma acquiring viscosity by loss of gas, crystallizing while in motion, doing this in fissures, consisting of deflating olivine basalt changing temperature from 1300° to 1000°C., the inflation having been with $CO_2 + H_2$, it is obvious that no quantitative experiment can handle this by physical chemistry, except in the field. The same is true of physics for epicenters; the engineering experimenter has learned to set up with the aid of those who dwell over the epicenter. The same is true of sea bottoms, the engineering experimenter can penetrate them. The conquests of astrophysics were done with the stars, which have been made optically accessible to engineers. The sea-bottom rock is available for contact and collection if an equal expenditure of engineering skill is applied.

PART 6.—PRINCIPLES OF CRATER EVOLUTION

EARTH THE OFFSPRING OF THE SUN

POSITIVE AND NEGATIVE DEVELOPMENT

The three contributions from a volcano observatory concern material collections, seismology, and evolution of vents. As the monthly reports are issued under stress during routine observing, the cyclical evolution aspects are neglected. The present paper has presented the surveys of Kilauea Crater in sequence and accents magma as affecting crater development. The illustrations here aim to make intelligible the monthly reports and to summarize a long history statistically.

The writer began this paper in 1910 after visiting Pelée, Soufrière, Vesuvius, and Bogoslof; and Hawaii, Japan, and Central America (Lacroix, Anderson, Perret, Jaggar (1908a; b): Brun, Daly, Koto, Simotomai, Jaggar (1911), Spofford, Pittier). By study of the moon's face and reviewing thereby the work of Ritchey, Shaler, Sacco, Suess, and others, and comparing the writings of Von Buch (Geikie, 1903, p. 263), Scrope, Judd, Bonney, Dutton, and Dana, he came to realize that the ultimate origin of volcanic vents is important in historical geology.

Crater classification was confusing. Steam explosion and magma effusion were not separated. A geyser remained where Tarawera (Smith, 1887; Grange, 1937) had erupted volcanically, and the "liquid lava" volcano Kilauea had "exploded" in 1790. When the Pelée spine appeared in Martinique, and Soufrière of St. Vincent (Jaggar, 1902; Anderson and Flett, 1903) showed no magma flowing, it was evident that Pelée achieved extrusion, the other intrusion, and that both achieved steam blast. Intrusive magma played an important part in the drama of opening craters, but one crater was a flank chasm, and the other a central pit.

Origin and development of craters is illustrated, on many scales, when magma effusion or intrusion at new or old fissures is mapped and measured in relation to the passage of time. The magma builds up, or by withdrawing and admitting ground water breaks down, an old vent exhibiting a geologic history. These are dynamic events, not structures. In Hawaii the crater is a strategic unit for experimental volcanology. Earthquakes, tremors, elevations, and tilts occur there that are undetectable 30 miles away. Gushings build up the sink floor and end with outflow 10 miles away on the mountain flank. The outflow creates a miniature crater with features that throw light on the mechanism of the larger sink. The study is not geologic deduction, but a plotted succession of changing profiles.

Magmatic process has downward or minus development (Jaggar, 1925) and upward or plus development. Negative movement has been shown all through the Kilauea narrative from Dana's time onward, but do geologists ever discuss minus or downward drainage of plutonic intrusives? A new rupture deep down may easily drain older fluid high up. Weighting by congelation is a large process at the basalt volcanoes. Do geologists ever discuss weighting by intrusive congelation within the oceanic mantle of the globe, that may be quantitatively more important than the weight of sediments?

Minus development of a crater proceeds by quiet engulfment; the magma flowing underground is doing constructive work of either intrusion or effusion. The magma returns to the crater, and the minus episode proves to be only a phase. The precise instruments of science are challenged to follow the magma under ground or under sea. The profiles of crater evolution show spots on the surface of the globe sensitive to intrusion. Both Hawaii and Japan have been led to minute study of precise levels and tilt (Imamura, 1930; Wilson, 1935).

The surface at a crater is trembling and changing its level and slope over intrusive magma. Geophysical prospecting will eventually reveal the form of the subjacent magma bodies. The available methods include measurement of gravity, sonic or seismic sounding, tilt, temperature, gas emanation, magnetism, earth currents or resistivity, leveling, triangulation, sounds, and the earth tide. Reconnaissance of some of these has been tried in Hawaii, showing crater ground excessively seismic, varying in magnetic constants, with shifting vapor temperatures, tilting seasonally and eruptionally, changing level by whole meters close to the active pit, but showing less but graded level change and tilt a few kilometers away. Triangulation shows horizontal shifts apportionate to eruptive tumefaction and collapse. Probably every solfataric belt can reveal intrusive movements geophysically.

GEOGRAPHIC EXPERIENCE

Thanks to the generosity of the late Alexander Agassiz and of subscribers to expeditions sent by Harvard University and the Massachusetts Institute of Technology, the author studied six volcano districts between 1902 and 1910 and has dwelt beside the Hawaiian craters since 1912, making excursions to six other major volcano chains. He has seen about 60 of the 450 active volcanoes on earth.

The twelve districts visited are typical of wider areas than the immediate regions named. Hawaii represents the high-temperature liquid-lava volcano found also in Samoa, Tonga, Reunion, at Kivu in Africa, and in Iceland. Vesuvius combines ash and viscous-lava eruption, seen also in Mexico, the east Atlantic islands, Kamchatka, New Hebrides, and the Philippines. Stiff lava low-temperature plugs and pastes of Japan are equivalent to similar extrusions of the Aleutian Islands, Java, the Aegean Sea, Guatemala, Martinique, and submarine volcanoes of the Pacific border that lead indefinitely into the ocean depths. Other Alaskan, Caribbean, and Central American vents present a series of underground magmas and steam blasts, leading up to the snowy Cordilleran cones, such as were studied by Reiss and Stübel in the Andes.

AGE OF IGNEOUS MATTER

A thermal gradient exists everywhere presumably, but it has not been measured in the rock crust under the ocean—that is, under three quarters of the earth's surface. It is there suspected only because seismic phenomena occur there, and seismic phenomena on ocean islands and borders accompany volcanic magmas, and volcanic magmas of olivine-basalt type are notably thermal. All other data for thermal gradient under the sea are based on deductive cosmology. Low temperature within a rigid earth is current doctrine that seems inconsistent with present-day worldwide intrusions.

The thermal gradient varies in continental and island borings, the variability being controlled by proximity of hot magma, of convective waters, and of expansive gases. Conductivity of rock is not highly variable, and frictional heat due to strain or motion from internal stress is a possible control, not probable within human diggings.

Increase of heat in depth is inherited from a hotter primitive earth spheroid. So is magma. Basaltic dikes cut through sediments, gneisses, and granites in the deepest erosion trenches. Rittman (1936, p. 172) agrees that olivine basalt lies under the mantle. This fluid is older than the oldest granitoid gneiss that its offshoots transect in that its inherited solar thermal matter has never cooled. Geology speaks of "younger" intrusions cutting others. But every new lava on the surface consists of material more ancient than any rock ever before revealed. If assimilation were involved the lava would be composite like a sediment. Otherwise, where deep magma is flowing forth today, the geologist may see and study pre-Archean earth particles in process of consolidation.

The geologic column is the latest time unit to the volcanologist, and it is purely continental. Erosion, sedimentation, and life are makers of mere surface in mantle history. Thin igneous skin upon the solar-matter sphere was formed incidental to the greater history of the deep shell. The oldest igneous matter congealed in the later *but not younger* lava outpourings is on the outside surfaces of the volcanic beds that are probably most extensive on and under the mud of the vast ocean-bottom global surfaces. The oldest igneous matter on the inner intrusion side of the mantle is the latest magma used in the much greater process of mantle growth downward if it is true that the earth is cooling. And the still older matter is progressively liquid, gaseous atomic, and ionized amid the mountainous accretions downward of whatever may be the bottom side of the thick shell of our sphere. The most primitive lava of pit or outflow is that remaining uncongealed and uncontaminated by air, gravel, wall, or water.

Differentiation of earth nucleus must ever be going on, and geologic time is but an incident, as contrasted with the hundreds of millions of years which the earth has had and still has at its disposal for evolving its atomic forces. Shallow remnant volcanism the author combats.

PRIMITIVE EARTH

The moon, presumably parted from the earth when the earth mass was still plastic, is a fragment of the primal globe. The early earth was more lunar-volcanic than it now is (Pickering, 1907). As some moonlike craters in maximum activity now exist upon the earth such as Savaii, Mauna Loa, and Nyamlagira, and others swamped under ocean may exist, while others in minimum magmatic activity are snowy peaks of different habit, it appears that volcanicity in stages of decadence exists and that the lunar sequences are primitive.

Study of crater evolution is aided by erosion sections. If primal volcanism was widespread and more active magmatically, its topographic creations were larger and graded in series, as on the moon where erosion was arrested by loss of water. This with due allowance for the sixfold greater fling and foaming permitted by lunar gravity.

The traces of primitive volcanism on the earth may appear in circularity of larger topographic features like the Himalayan and Sunda arcs. The series may be still traceable in chains of islands, continental borders, ocean deeps, mediterranean seas, ocean ridges, curvilinear grabens, arcuate Sommas, and gigantic craters of engulfment like Asosan or Aniakchak.

The earth-moon comparison from the viewpoint of volcanologic geography appears worthy of more systematic study than has been given it. Viewing volcanicity as a surface remnant of what is now intrusive continuance of the primitive process, it is certain that through the hundreds of millions of years old vents have closed, and reopening may be a matter of cycles of 25 to 40 million years. The place of such reopening is along the great contacts such as the seismical border of the Pacific and the features that originally determined permanence of continents. Between these features extend ignisepta, giant rift belts full of magma, leading down to centrosphere.

If the shell of the globe were originally covered with many extrusion vents, now disguised chiefly over the 28 per cent of the earth's surface which is continental, and less disguised except by water under the great oceans, then original volcanic belts are still effective on the surface, and complete topographic maps of the ocean bottoms may reveal physiographic features comparable to the moon.

The symmetries on the moon's face of first importance are circular, or subcircular pentagonal, and on all scales from small pits to concentric faulting at the edge of the Mare Imbrium. The bright-line symmetry around such volcanic centers as Tycho are radial and straight-chordal, and on a still greater scale than the concentric symmetry of some of the maria. As relics of process it is unquestionable that the larger lunar craters are sinks, that lines of small pits follow the downfaulted arcuate traces of buried sinks gradationally (Clavius), and that the alignment of pits along faults discredits theories of general meteor impact.

To the volcanologist who goes back 2000 million years and farther to an earth that was parent to the moon and to a sun that was parent to both, it is reasonable to look for lunar symmetries on our globe and to look for solar processes in the centrosphere. This is the realist philosophy of geology, that believes in the measurements of the present and the earth theories of a century hence, after we have some facts about the rock globe of the sea bottoms. We are justified in comparing earth and moon, with due allowance for the differences of gravity. The primitive earth was presumably at one stage like what is now seen on the moon. There are fewer magmatic craters on the earth today than in the primal volcanic period, but they exist in Hawaii, Iceland, Reunion, and Central Africa, and they may exist in large numbers on the sea floor, with such modified activity as a coating of sediment and water may give.

Important quasi-lunar structures, now concealed under water or sediment or metamorphics, may be the vents which led upward at one time to craters. In some cases the constructional rings above, created by shrinkage and sinking, may have been destroyed, and the vent filled with solidified igneous rock, but the physiographic rings and radial chordal cracks along straight lines may be preserved on a large scale. The smaller-scale features like Clavius or Plato might well be found in the central Pacific, when sonic sounding has made a topographic map. The time element of cycles of construction and destruction varies with the size of the volcanic unit constructed. The cycle of an Aleutian or Carib or Sunda arc is an affair of geologic ages; that of a many-cratered island is an affair of geologic episodes; that of a dominant volcanic system in action may lie within supercycles measuring thousands of years between recurrent major earth crises of intrusion; while single volcanic domes lead the observer to cycles that come within human estimate of luni-solar stress and astronomically measurable time units. From the globe to the spatter cone we deal with increasing frequencies and decreasing size of magmatic wave motion or pulsation.

Persistent ruptures or ignisepta along general zones, within the oceanic areas and about their periphery and perhaps along shearing planes determined by gravity stress in a very early stage of the consolidation of the globe, have maintained volcanic vents in a condition of activity at approximately the same places on the earth's surface for long periods of time. Under the oceans this permanence has existed from pre-congelation time to the present. The water pressures and low temperatures and mud coverings of the bottoms of the deep oceans are sufficient, along with man's present ignorance, to mask an active volcanism there within bounds totally unknown to science.

So far as the very brief and localized continental story of the geologic column goes, volcanism has been on the wane as a whole, and the early earth, long before the Archaean, was covered with clefts, volcanoids, fissure eruptions, and broad igneous maria like the moon. It may be assumed that the sometime lunar earth has given place to an earth with three-fourths of its volcanic fields under water, and much of the remainder drowned under the deposits of epicontinental seas and there transformed by batholithic assimilation and differentiation within ruptured geosynclinals.

LUNAR COMPARISON OF PACIFIC ARCS

It is customary in geology to consider arcuate lines of islands in the eastern Indian Ocean and Caribbean Sea and in the northwest Pacific as tectonic. Referring to the Mare Imbrium, however, in its relation to the scale of the moon's face it is of interest to note that it lies along a belt of subcircular maria of different sizes, and along its border Plato lies along a group of subcircular bays. The phenomenon of marginal cracks of a larger feature generating more perfect circular volcanoids of later activity is well known on several scales on the moon (Spurr, 1944).

Studying the western Pacific on a globe we find the north-south trend of the Bonin and Ladrone (Marianne) islands a rough curve that starts southward from Fujiyama, and if prolonged as a circular curve about a center in the region of Mayon volcano with a radius of approximately 24 equatorial degrees we shall follow a remarkable circular arc of active volcanoes through the Banda Sea, Java, Sumatra, and the Andaman Islands. The extension of this circle into central Asia intersects the Himalayan arc and some earthquake and hot-spring districts. There is here a circle of volcanism, with its center in a volcanic belt and of diameter more than a third of the earth's face. (*See* Bellamy, 1936, Fig. 1, showing circles of epicenters in Java-Japan, East Atlantic, North America.)

Going north from this large circle, the four well-known volcanic arcs are Riu-kiu, Japan, Kurile, and the Aleutian curve, of progressively greater radius like the inner pits of Clavius, and with the line of their centers nearly straight from Nanking to the Gulf of Anadir. The centers are now continental, and the northwest semicircles are lost in a plexus of epeirogenic structure. The series of inner seas in a straight line, bounded by circular curves of active volcanoes on the Pacific side, is suggestively like lunar features and lunar circular volcanic symmetry inherited from the primitive earth. The Philippine center is off the straight line, and its line of epicenters is remarkably diametral to the Sunda Arc (Bellamy). From Cocos Keeling through Krakatoa to Mt. McKinley the collective arcs lie nearly on a great circle.

WORLD VOLCANICITY INDEX

In view of all the tectonic foreland arguments of Suess and Wegener, it may be complained that this reversion to a lunar earth disregards all the excellent orogeny of the Alaskan, Japanese, and Netherlands geologists. It does not do so. Volcanology goes farther back than all orogenesis. Modern seismometry finds (Gutenberg, 1939)

> "the boundary of the true Pacific Basin is outlined by the earthquake epicenters. On the west side it runs east of Japan, the Marianne (Ladrone) islands, the Palau islands, thence towards the islands of Samoa which are on the Pacific side, and then turns southward near the New Hebrides leaving the Kermadec islands and New Zealand on the 'continental' side. On the American side the boundary is close to the coast. The fact that the foci of all earthquakes originating deeper than two hundred miles have been found close to and on the continental side of this boundary indicates that the Pacific Basin has a unique structure. There is a limited area with continental structure in the southeastern part of the Pacific, and another of Pacific type of structure in a part of the Arctic Basin."
>
> "All evidence agrees with the conclusion that the layers which formed the uppermost crust in the continents are lacking in the Pacific Basin. The belt surrounding the Pacific Basin is characterized by faults in great number. Earthquakes originating at depths from close to the surface down to several hundred miles and the existence of relatively large gravity anomalies in many of the areas involved leaves no doubt that this belt is the most active region of the world and that changes are going on in it extending from the surface to a depth of a few hundred miles at least. These processes, on which local changes are superimposed, seem to persist in their directional characteristics over long-time intervals and over large distances, of at least notable fractions of the Pacific boundary. The source of the energy and the mechanism involved are not known but it seems very likely that sub-crustal currents, perhaps due to thermal processes and the difference in structure between the Pacific Basin and the surrounding regions, play an important role."

These evidences from up-to-date seismology and terrestrial gravity, added to the findings of volcanology, amply justify the doctrine of permanence for true ocean basins as features much larger than anything seen on the moon, and possibly accordant with George Darwin's (1898, p. 282) notion that the moon parted from the earth when the earth mass was still plastic, and that it is a fragment of the primal earth. It is a question of interest whether the subcrustal magmatic currents suggested by Holmes (cited in Daly, 1933, p. 226), Daly (1933; 1938a), and Gutenberg, and the subcrustal intrusion up deep rifts accented in the present paper, along inherited local lines of fissuring or about centers of volcanic outpouring in the primal earth shell, may not be the real cause of many large earthquakes. Volcanicity may thus be considered an effective agent in all diastrophic processes, and every region on earth, near or remote from active volcanoes, may in some sense exhibit a measurable index of volcanicity when we have learned how to measure it. Below in the rock crust there may be the structural potencies of a primitive volcanoid to make a difference seismically, thermally, by gas emanation, or by magmatic water condensation, in the present surface ground.[10] Even in the stable nonseismic lands of maximum population local geophysical tests or mappings by sonic sounding may reveal far below in the underearth the center or outline of a primitive terrestrial volcanic sink, resembling one of the craters on the moon. Much more is to be expected from critical instrumental measurements, when a geophysical laboratory is permanently anchored in an ocean, with electrical communication to the bottom under 2000 fathoms of water, to expend the lifetimes of a scientific staff on experiments, thermal-gradient determination, and petrologic collections, directed to the rock bottom of the muds under the sea.

TIME AND PLACE METHOD

With all that has been observed and written of the moon, and of the heavens, from the time of the Pharaohs, it is singular that the earth has so little been studied distributively as a laboratory of physical processes. The admirable seismical survey of Japan which has now been carried on for 50 years has been supplemented there by experimental studies throughout an extended period of time, of individual Japanese volcanoes, of ground-surface movements, of thermal change, of gravity, and of magnetism. The honored names of the late Bundjiro Koto and Fusakichi Omori bear witness to unrivaled geological and physical achievement in this field.

Palmieri, Matteuci, Mercalli, Malladra, Imbo, and Signore on Vesuvius, Ricco and Platania on Etna, Stehn and all his predecessors in Java, Perret and the French Observatory on Martinique, and the United States Government in Hawaii and Lassen have maintained permanent volcano stations. Many others have conducted temporary or repeated investigations of volcanoes, making advances by the expedition method, in determining practical methods of work. Engineers investigating catastrophes in the last 40 years have done good service in increasing preparedness. All of this, however, has not scratched the surface of the scientific possibilities for the observatory method in volcanology and in seismology.

From the days of Palmieri and John Milne, the bright prospect of harnessing the surface of the earth with empirical measurement directed locally and geographically, and including the sea bottom, was matter to excite the imagination of the geophysicists. A sea-bottom observatory, making measurements by wire automatically for a scientific station on land 50 miles away, is entirely feasible but not yet attempted. There are many islands in the sea where this might be done, and there are exciting possibilities of addition to science, whereby this might be done better from an artificial island. Only when these things have been attempted, and when more nations have followed the example of Japan, will science know what a true epicenter is and begin to have some inkling of what happens at an earthquake focus in depth.

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[10] Sampling surface soil is said to detect oil. May it not detect subjacent magma?

CURRENT GEOPHYSICAL DOCTRINE

In the volume of special bulletins of the National Research Council entitled *Internal constitution of the earth* by Beno Gutenberg, chapters are collected by different authors to show current physical and chemical hypotheses by specialists in astronomy, geology, chemistry, seismology, and physics. The supposition is that the earth was originally liquid, that metallic matter (largely iron) settled to the center, that meteorites give us a clue to what a disrupted earth would be, and that the chemistry of the surface features of earth and sun is parallel to the chemistry of the earth's core. The core is estimated to have a radius of 3500 kilometers, and the silicate shell or mantle extends the radius to the surface of the earth by a thickness of 2900 kilometers.

Seismology indicates that there are discontinuities, except under the Pacific and Arctic oceans; at 20 kilometers of depth under the Atlantic and Indian oceans, 40 kilometers under the continents, and there is a change in physical properties 500 to 700 kilometers down, where the deepest large earthquakes are believed to originate; here electrical conductivity increases rapidly. There is a change to greater density at 1000 kilometers depth, and at 2900 kilometers occurs transition to what is believed to be liquid because of the failure of the core to transmit rigidity waves where compressibility waves go through.

There is believed to be a world-encircling shallow shell of basalt, above which lies continental granite limited to the land masses. The basaltic shell is the supposed world of volcanism.

That the deep layers can be other than stratoform, in onion structure, and that persistent intrusion from core interrupted their formation from the earliest days would disturb mathematical postulates. The volcanologist would interpolate that none of these allows for a kinetic changing world of deep intrusion at the present day, unperceived because not hypothesized. The unperceived under sea and crust is the main aim in devising working hypotheses guiding experiment and measurement. The localized crater is precious. Localization in the other specialties is rarely practiced, except where navigation, radio, aviation, oil, or cables demand it. The epicenter, sea bottom, river, precise equator and pole, and the strategic shore line are not yet equipped with standardizing inventive permanent observatories.

There is thermal conduction through the crust, and subcrustal currents are believed to favor the thickening by mountain folds and the production of continental drift. The inequalities of the earth's surface layers add to the stresses produced by possible slow convection currents where it may take 100 years or more to produce plastic flow.

Cooling is in progress but is reduced by the heat of radioactivity, and the earth's crust has not cooled steadily. Mathematical calculation makes the surface-temperature gradient average 20°C., the deep gradient 8° per kilometer, and the temperature at the core may be as low as 3000°C. (1200° less than the boiling point of carbon), according to Gutenberg, who, however, is unconvinced.

There is irregularity in the velocity of elastic waves in the deeper parts of the mantle. The density increment is estimated to be from 2.75 at the surface to 4.5

at 1000 kilometers depth, 7.0 at the boundary of the core, and 12.0 at the center of the earth. The gravity constant in the mantle decreases to 0 in the core. The pressure is 1 million atmospheres at a depth of 2000 kilometers, 2 millions at 3500 kilometers, and 3.5 millions at 6400 kilometers, the center of the earth. The bulk modulus (reciprocal of the compressibility) increases in the core (compressibility lessens), and the rigidity increases down to the core, wherein it is presumably smaller.

Isostasy teaches that the strength or resistance to plastic flow is less below the surface, but there is no precision to definitions of strength, viscosity, internal friction, and creep. There is disagreement as to major forces, no agreement as to whether more heat is produced than escapes, and contraction is doubted. Special hypotheses are being proposed rapidly.

Explanation of deep-focus earthquakes, known only in limited regions of the Pacific border at depths of 250 to 700 kilometers, is shearing stress and rupture. Present seismic belts are narrow, of large minus gravity anomaly, and where tectonic movement is now in progress. Tertiary tectonic belts show focal depths of 60 to 250 kilometers, and volcanic belts show clustered earthquakes at 100 kilometers depth. There is notable seismicity along the medial north-south ridge of the Atlantic.

Geophysical doctrine is mostly based on empirical data from continents, assumptions derived from a cooling isotropic globe treated mathematically, and experimental measurements of physical chemistry of silicates, thermal gradients, seismograms, gravity pendulums, electro-magnetic surveys, elastic constants of rock specimens, and on theory of earth origin by solar collision, tidal theory, and the theory of isostasy. Analogy plays its part.

Increase of electrical conductivity at 500–700 km. depth suggests to the reviewer segregation of iron, nickel, and copper (atomic weights 55, 58, 63) as original volatiles now clustered solid near the surface, still vaporous on the sun, and near enough to us to have been the source of Ovifak iron basalt in Greenland. These are relatively light weight metals, if we disregard surface abundance. If that superficial hard shell 600 km. thick were disrupted it might be analogous to meteorites. But not the core, where both sun and earth may preserve heavy matter not at all atomic or ferruginous. There is a tendency in physics to dismiss as untrue the unperceived, even when so gigantic and near as the earth's core. Nevertheless, science begins at home. Stuff of atmosphere, hydrosphere, and lithosphere is presumably matter discarded by process of the ages.

Clarke and Washington (1924, Table 11) show most of the heavy metals of atomic weight exceeding 100 to be rare in the crust; they find (p. 71) 99.5 per cent of the crust made up of 13 light elements below atomic weight 57, discarding decimals, in a rather evenly graded series, as follows:

Hydrogen	1	Phosphorus	31
Carbon	12	Calcium	40
Oxygen	16	Potassium	40
Sodium	23	Titanium	48
Magnesium	24	Manganese	55
Aluminum	27	Iron	56
Silicon	28		

These are all within the first 26 atomic numbers and affiliated with radioactivity.

On the other hand these authors indicate that deep olivine rock dunite of the Urals bears the six elements of the platinum group in the order of abundance of their atomic weights (p. 27, misstated as inverse). Hawaiian basalt carries dunite inclusions. The writer comments that perhaps the heavy metals give a hint of the order in the core.

CLASSIFICATIONS IN VOLCANISM

J. W. JUDD 1881

Judd diagramed (1881, Fig. 77) a series of lava and cinder cones from terrestrial volcanoes, illustrating classification of craters which was current among geologists, describing the figure as showing "the various forms assumed by volcanoes in consequence of the different kinds of eruptive action going on in them, as follows:

1. Outline of Fujiyama, an almost perfect cone, with small crater at its summit, its sides illustrating the beautiful double curves characteristic of volcanic cones.
2. Hverfjall in Iceland, a volcanic cone with large crater, its bottom almost as low as the base of the mountain.
3. Crater lake of Bracciano, Italy, with area of crater very large and walls very low.
4. Rocca-monfina, in southern Italy, a large tuff cone in the midst of which an andesitic lava heap has been built up.
5. Teneriffe, Canary Islands, with a perfect volcanic cone built high in the center of an encircling crater ring.
6. Vulcano, Lipari Islands, where by the shifting of the center of volcanic building along a fissure line, a series of overlapping volcanic cones was produced.

Judd also figures the contrast between Mauna Loa, Hawaii, a flat shield built by very fluid lava, and the Schlossberg of Teplitz, Bohemia, built by stiff viscous lava.

He notes among terrestrial volcanoes spiracles, scoria cones, pumice cones, tuff cones, lava cones, composite cones, parasitic cones, crater rings, crater lakes, mud volcanoes, and sinter cones. Composite cones were believed the most common, including Vesuvius, Etna, Teneriffe, and "most of the great volcanic mountains of the globe."

Judd offers an explanation different from Dana's for the concavity of cone profile curvature as follows:

> "The piling up of materials along the volcanic vent causes the subjacent strata to be subjected to a degree of pressure far in excess of that which acts upon the surrounding rocks. And secondly, it must be borne in mind that the continual removal of material from within the mountain must tend to the production of hollows, into which the overlying strata will sink. The effect of this central subsidence is to give to the flanks of volcanic cones those beautifully curved outlines which constitute so striking a feature in Vesuvius, Fujiyama and many other volcanic mountains."

This process is in substance what Dana called "down-plunges consequent upon undermining," but he did not apply it to strato-volcanoes or composite cones.

The school of geologists led by Lyell, Scrope, and Judd have made much of the explosion origin of crater rings, of which Monte Somma on Vesuvius is the type. This doctrine requires close scrutiny, and accordingly some citations from Judd *in extenso* may serve as a basis for discussion; it must be remembered that Judd's *Volcanoes* was written before anything was known of Krakatoa (which he himself later studied), Pelée, Tarawera, Bandaisan, Bogoslof, Santa Maria, Savaii, or Tarumai, and that his school of volcanological thought was more influenced by the extinct volcanoes of central France and of Bohemia than by such very active vents as the lava pits of Hawaii. The example of Vesuvius in 1872 and the story of Papandayan, said to have been reduced in height 1200 meters in a single night, made a profound impression on nineteenth-century geology, and great crater circles were attributed to explosion. Judd wrote (p. 170), "In some cases, indeed, the whole mass of a mountain has been blown away during a terrific eruption, and the site of the mountain is now occupied by a lake." He cites such crater rings and crater lakes in the Phlegraean Fields, the Rhine provinces, the Auvergne, Mexico, and central Italy:

> "in these great circular lakes of Bolsena and Bracciano, as well as in the smaller ones of Albano, Nemi, and the lakes of Frascati in the same district, the vast circular spaces enclosed by them, the gradual outer slope of the ring, and the inner precipices which bound the lake, all afford evidence of the explosive action to which they owe their origin."

Circular form, terraced slopes, and precipices all occur in the Hawaiian volcanoes, and generally without steam-blast explosion. These features afford no evidence whatever of explosive action. The great known explosion craters, such as Tarawera, Krakatoa, Pelée, and Bandaisan, are chiefly remarkable for the absence of circularity and regularity and for definite accompanying engulfment. Lake Toya (Omori, 1911) in Hokkaido is a wonderfully circular lake and has moreover a central volcanic island, but the volcanic geology of its shores is diverse, and its circularity is wholly unexplained by any crater-ring theory yet devised. Lake Toba in north Sumatra is similar and described by Van Bemmelen as due to "blow out-breakdown" (1919).

The craters cited are supposed to be confined to structures of volcanic tuff and dust. The true Somma rings are more often hard basaltic or andesitic rock, ancient lava layers, and perhaps the rims of ancient lava pits of engulfment. Judd cites stages from the crater-lake phase to Vesuvius:

> "Sometimes, as in the case of the Lago di Bracciano, the eruptive forces appear to have entirely exhausted themselves in the prodigious outburst by which the great crater was produced. But in other cases, as in that of the Lago di Bolsena, the eruptive action was resumed at a later date, and small tuff-cones were thrown up upon the floor of the crater; these now rise as islands above the surface of the lake. In other cases, again, the eruptive action was resumed after the formation of the great crater-ring, with such effect that bulky volcanic cones were built up in the midst of the crater-ring which surrounds them like a vast wall; examples of this are exhibited in the extinct volcanoes of Rocca Monfina and Monte Albano. Some of the grandest volcanoes of the globe, such as Teneriffe, the volcanoes of Mauritius and Bourbon, and many others that might be cited, are thus found to be surrounded by vast crater-rings. Vesuvius itself is surrounded by the crater-ring of Somma."

Judd's figures show Teneriffe and the volcano of Bourbon (Réunion), the latter showing a ring over 6 kilometers in diameter encircling the active cone, and again three concentric rings at progressively greater distances from the base of the inner volcano. These types may be compared with descriptions of other sommas, and with the volcanic series proposed by Stübel. We should not confuse totally different structures in classifying together crater lakes, crater rings, and sommas as they occur on the earth. Such volcanoes as Vesuvius do blow away parts of their summits, enlarge their craters by engulfment, and form new cones within old craters. There is question, however, whether Monte Somma is a case of explosion. Volcanoes may pass crises in their building whereby an ancient quiet lava process of upwelling and engulfment is replaced by composite lava ash and explosion processes. When the

Somma wall is all tuff, conditions are different from those cases where it is mostly lava. Réunion is by all accounts a place of lava eruption, and a crater ring there one would suspect of being the wall of a sink or pit, even more probably than in the case of Vesuvius. The crater of Lago Bracciano may be an explosion pit of some kind, but like Crater Lake it is more likely to be a combination of destruction by engulfment, accompanied by moderate phreatic steam blast (Volcano Letter No. 451, September 1937, Origin of Crater Lake Cup).

C. E. DUTTON 1884

A philosophical statement of "the volcanic problem" by Major Dutton occurs in Chapter XI of his memoir on Hawaiian volcanoes (1884), illustrated by the splendid drawings of W. H. Holmes. Major Dutton was sent to Hawaii by the United States Geological Survey from May to November 1882. Originator of the doctrine of isostasy and opponent of contraction, Dutton was an engineer trained in physics and competent to discuss the physical meaning of the larger problems of geology because of extended experience with uplift, denudation, and volcanic outpourings in the plains, plateaus, mountains, and rivers of the American Southwest.

Dutton notes that the volcano is a heat problem in a rigid earth whereon there is evidence of plastic deformation. In the penetration of water, vesicularity of lava, and explosive phenomena, for absorption of steam by liquid lava to complete saturation, we must take account of temperature of the lava, pressure of the gas, and the capacity of the lava for such absorption. If stable equilibrium results "the access of the vapor of water to hot lava, within the earth, could not produce a volcano unless followed by increased temperature in the lava or by diminished pressure." He discusses geyser mechanism as homologous with the volcano and finds objections. The penetration of water vapor is a special case of diffusion of gases, and the geyser is produced by the sudden access of a large body of cold water to a heated void. No void can exist in the region of red heat and plasticity 8 or 10 miles vertically downward.

Dutton was impressed by the enormous loss of heat at Mauna Loa and Kilauea, the proportion of heat diffused and dissipated between eruptions, and believed "we are required to find a supply of heat which shall not only convert the lavas from an inert condition into an energetic one, but supply the vast additional amount which is slowly let off and wasted." Also, as shown by Charles Darwin, in general the platform under volcanoes is bodily rising, so that volcanic action does not mean an uncompensated loss of original heat. With reference to the geyser hypothesis as a source of localized energy, and conduction of heat upward to meet downward-filtering ground water, wherein preliminary cooling of lava will be essential to the subsequent reheating, Dutton concludes that the conduction of heat is too small, and the heat resident in the lava itself is too great.

He next considers chemical hypothesis based on the conception of a cold and stable crust, with metallic bases inside, elementary or in the state of sulphides, and the atmosphere penetrating to depths capable of generating volcanic action by oxidation. Major Dutton arrives at the following singular conclusion: "Either the earth's atmosphere, which has supplied all this oxygen must in former periods have been greatly different both in quantity and constitution from what it now is, or else the earth is acquiring oxygen in its march through space." Dutton cannot conceive of sudden decrease of pressure as a cause of eruptions and apparently did not think of an increase of pressure due to weight of lavas over a steady ascensive force. He was convinced that the source of lava and its heat is shallow. Apparently the conception of oxygen still emerging from the centrosphere was to him inconceivable.

Dutton dismisses the mechanical crushing of localized crust material by wrinkling of the shell and contraction of the core of the earth through loss of original heat as follows: The facts adduced indicate that the only cooling has been in the outer thin crust, while the nucleus is as hot as ever. But, if the nucleus has not cooled, it has not contracted; hence the hypothesis is its own refutation.

Dutton's fourth hypothesis (after water, chemistry, and tectonics) suggests that heat is generated locally to produce volcanism by a hitherto undiscovered cause. "It is a simple appeal to a mystery. I am strongly imbued with the hope that science will some day close the missing link." This prophecy led Dutton at the beginning of the twentieth century, after radium was discovered, to consider radioactivity the missing link. He greatly overrated it (Louderback, 1906).

Dutton's fifth supposition was that denudation could release pressure by removal of material and that the highly vesicular hot matter of the interior of Mauna Loa

> "floats high because its materials are of low specific gravity. It seems as if the summits of the lava columns in Kilauea and Mauna Loa were approximate equilibrium levels dependent upon their mean density at any given time. The visible effects corresponding to increase of temperature of lava column would be enlargement of the area of the lava lakes and possibly an increase in the amount of gas and steam given off. The rate of dissipation of heat would depend mainly upon the rapidity of convection up or down the column: the hotter steam-charged lavas rising, the cooler steam-exhausted lavas descending."

This is Dutton's only mention of "gas" in his theoretical chapter, though he speaks of "jets of fire," "the burning lake," and "sulphur gases" in his descriptive chapters. The above discussion anticipates current theory strikingly. Dutton in the following words anticipated the conclusion of Brun that the Hawaiian volcanoes are among the hottest on earth.

> "The quantity of heat dissipated by these volcanoes is suggestive of the immensity of the supply. It is hard to reconcile this patent fact with the notion of a primitive reservoir charged with a definite quantity of heat which is slowly wasted without replenishment, yet giving no sign of exhaustion or even enfeeblement after accomplishing such vast results."

In his last page (p. 197) Dutton develops the intermittent feature of eruptions, as to rising and falling, heating and cooling, increasing and decreasing lava area, and changing in agitation. His answer to the question "Why should a volcano give forth many thousands of eruptions instead of a single eruption equal to the many thousands combined?" is that lavas in an underground reservoir gradually acquire and expend energy in one portion of the reservoir at a time, rupture the covering, and the whole of this portion is extravasated, when the vent closes. "The agency which thus progressively develops the potential energy or elastic force is the missing factor. When we discover it we shall discover the secret of the volcano."

The fulfilment of Dutton's prophecy resides in gas chemistry and the nuclear reactions of elemental atoms, truly an extension of the radium discovery. Physical chemistry has gone ahead by leaps and bounds since Dutton wrote. He was impressed by steam like all his colleagues and confused phreatic and magmatic phenomena. He realized intermittency, but not cyclical release of a constant force. His acceptance of a rigid earth was fashionable, but modern seismology accepts a "liquid" centrosphere. The conception by Arrhenius of compressed gas came after 1883.

J. D. DANA 1891

Dana wrote as follows concerning original vents (1891, page 149):

"The crater of a great volcano has its beginning in a discharging fissure or in the crossing of two fissures: and it continues open until a temporary or final decline of volcanic action, whatever the kind of volcano. It continues open, (1) because of the lava column, (2) because of the conduit work going on through it in the discharge of vapors and lavas, and (3) because of the down-plunges in the crater consequent on the undermining which the discharge of the conduit occasions. The open end of a deep-reaching lava-column determines thus, by its discharges and the subsequent underminings, the existence of the crater; and the crater, by the work done within and about it, makes the volcanic cone. This appears to be the order of rank or importance in the phenomena,—the crater begins in the opened fissure, and is the indicator and future builder of the cone. In the history of the volcano the era of summit outflows may pass, and only lateral discharges take place; and still the discharge of vapors from the lava-conduit and the accompanying movements in the lavas, together with the down-plunges in the crater following the discharges, will keep the crater or portions of it in continued existence, and the work of eruption or outflow, if subaerial, will be still adding to and shaping the cone.

"Examples in the Hawaiian Islands teach also that volcanoes may end with an open crater over two thousand feet (610 m.) deep, like Haleakala, a cone ten thousand feet high (3050 m.), or with a filled crater, as in the case of Mauna Kea, thirteen thousand eight hundred feet high (4209 m.)."

"The preceding remarks about the permanence of craters apply to other kinds of volcanoes as well as the basaltic; but in the form of the crater the basalt-volcano has peculiarities, owing to the mobility of the lavas and the paucity of cinder discharges. The ordinary crater of the basalt volcano is pit-like, with the walls often nearly vertical, and the floor may be a great, nearly level plane of solid lavas. The liquid material of the extremity of a conduit works outward from the hotter centre, through the fusing heat and the boiling and other caldron-like movements; and hence, where the mobility favors freedom of action in these respects, it tends to give the basin or crater a nearly circular form, with steep sides. Besides, when the discharge takes place there is usually a fall of the walls, which is still another reason for vertical sides and the pit-like form. Such pit-craters are normally circular; but where there is a large fissure beneath the crater they may be much elongated."

Dana does not discuss the craters of cinder-cone volcanoes, but he gives some attention to cones (p. 12):

"The lava of an eruption is discharged in portions at intervals of hours or days or weeks, and the streams become cooled at bottom and cooled at top, so that only the interior flows on in a kind of tube or tunnel, and this, as it emerges below, takes its chances of cooling. The streams are narrow strips down the cone. They come out usually from fissures, and at all heights between the top and the bottom. The resulting angle for a basalt-volcano becomes thereby 1° to 10°, and rises often to 90° in the driblet cone.

"With the less fusible lava the cones are of steeper angle than with basalt, since the high temperature of fusion generally fails of being supplied from the depths below, and is more easily lost by cooling; and the lava therefore is commonly more or less pasty. The andesite cones of western North and South America are 25° to 34° in slope.

"Since a cone diminishes in diameter upward, a flow of lava from near the summit having like width throughout would cover a much larger part of the circumference in the upper part than in the lower. The part of the cone below would require in fact a great number of ordinary streams to make one coat over the surface. The consequence of this condition is that such discharges make the cone steeper above, and give it a concave outline. But if the flows commence for the most part a little below the summit, from an eighth to a sixth of the height, the upper part would be widened and the cone take the form of a low dome, like Mauna Loa; or if the streams come from fissures in the lower part of the cone and spread beyond the base, the cone will be flattened below, and the lower part of the profile will be made concave. (In this discussion Professor Dana omitted the effect of the widening and thickening of flows down a slope under increasing viscosity due to progressive cooling. He cites experiments with sand and fluid mud to the effect that "such trials show that an angle of 40° is as great as should occur with dry cinders, unless the fragments are very irregular and light; that with fine dry sand it may be as low as 25°; and that an angle of 15° is not too small for a flowing mud, though steeper slopes may also occur.)

"Cinder-made cones are usually between 30° and 40° in angle; but they vary in height, breadth and slope on the different sides, according to the direction of the prevalent winds. Alternations of cinder and lava ejections will make a cone of steeper slope than lava alone; and this may be part of the reason for the high angle of slope of the volcanic mountains of western America. Summit ejections of cinders may increase height without adding much to the mass of a mountain. (Dana calls attention to the wrong impression given by the usual textbook cross-section of the bedding of a volcanic cone "since it seems to imply that the cone consists of a regular series of coats. In a tufa-cone there is a slope beneath the crater, as well as down the outer surface," meaning dip of bedding inward.)

"Ejections of volcanic cinders or ashes from the chief vent or crater of a basalt-volcano are generally of small amount; but they may make beds a thousand feet or more thick about volcanoes of other kinds.

"Lateral cones (p. 245) are a frequent result of eruptions on Hawaii and the other islands of the group, although the lavas are basaltic. They occur, as in other volcanic regions, along the courses of fissures, along a flow of lava where fissures for supplying lavas are underneath it, and also in and about the summit crater. Whether a lateral cone consist of lava-streams or of cinders (lapilli) depends on the supply of heat as well as of lava in the vent; and whether the cinders make cinder-cones or tufa-cones is determined by the supply of moisture connected with the eruption, much descending moisture giving a mud-like flow to the ejected cinders, whence the low angle and saucer-like crater of the tufa-cone."

Shaler's view of terrestrial volcanic vents was strongly biased by his insistence on a superficial source of volcanic energy in steam from water imprisoned in marine sediments. To him the explosive volcano was the fundamental terrestrial type, and the lunar volcanoids were not intimately comparable with anything on earth. Dana, on the other hand, was influenced strongly by Hawaii, and to him the liquid-basalt mechanism furnished the basis for all volcanic theory. Like Shaler, however, he adhered to the doctrine that water vapor was the prime control in volcanic activity and that by vesiculation it might partly at least account for the projectile and ascensive force of the lava and the discrepancy in height of the Mauna Loa and Kilauea lava columns.

A. GEIKIE 1903

Sir Archibald Geikie is an example of the conflict of opinion that has raged around the word "caldera." To Stübel a "caldera mountain" is a fundamental form, made of lava, and left by engulfment and is found in all the ring craters on the moon and in all the "Sommas" of the earth. Geikie, like Judd, assigns an explosive origin to Monte Somma without any question and even as late as 1903 unhesitatingly dates it from the Plinian eruption of Vesuvius in the year A.D. 79. The following are some citations from his textbook, probably the most comprehensive manual of geology ever written, and yet in this respect in no way eclectic. "The Valle del Bove on the eastern flank of Etna is a chasm probably due mainly to some gigantic prehistoric explosion" (p. 290). Santorin, Monte Nuovo, Krakatoa, Tarawera, and Bandaisan are cited as other examples of calderas of explosion. On another page (324) Geikie attributes to explosion the crater lakes of the Eifel, Central Italy and Auvergne, Coon Butte in Arizona, and the original "Caldera" in Palma, Canary Islands.

> "Many volcanic cones", he says in conclusion, "have been eviscerated by one or more gigantic explosions, the bottoms of their craters have been blown out, and sometimes as much as half of the cone has been demolished, leaving a huge, caldron-like hollow partially encircled by the remaining crater-wall, and bearing a far larger proportion to the size of the surrounding cone than an ordinary crater. Such a condition is known as the Caldera type of volcano, after the magnificent example of it in the island of Palma, one of the Canary group. This vast cavity is from three to four geographical miles in diameter, and is surrounded on all sides but the south-west by a range of precipices from 1500 to 2500 feet (458 to 762 metres) in vertical height, and rising along their higher summits to more than 7000 feet (2435 metres) above the sea.... The type is well illustrated among the Andes. In Ecuador, Dr. Stübel enumerates eleven examples of it. Of these the most perfect is Rumiñahui, the crater-wall of which rises upwards of 800 metres above the bottom of the caldera to a height of 4757 metres above the sea. In two cases (Guagna-Pichincha and Pululagna) an eruptive cone has been formed within the caldera. The great explosions of Krakatoa and Bandaisan have taught us how such vast caldron-like cavities may be produced within a few hours by sudden explosions. It is possible also ... that in some cases the depth of the hollows has been increased by a subsidence of the bottom, like that which appears to have occurred at Krakatoa."

Stehn (1929) has reinvestigated Krakatoa and found that its eruption was largely engulfment.

This statement by Geikie is a deliberate invasion of the camp of the enemy by the explosionist. Stübel's 11 cherished calderas of engulfment are cited most casually as calderas of explosion. The passing concession to auxiliary subsidence at the end of the paragraph is parenthetical and serves to strengthen the positiveness of the explosionist position rather than to weaken it. Dutton's use of "Caldera," for Hawaiian engulfment sinks, is wholly ignored. Geikie shows here the extraordinary power of Lyell's uniformism in its influence on English geological thought. What happens today is obviously the guide to what has happened in the past. Krakatoa and Bandaisan made great cavities; therefore all great cavities of the past were made as in the explosive or dramatic part of the mechanism of Krakatoa and Bandaisan. It is not an argument, it is an assumption, an inference, a necessary mode of thought.

This is the more extraordinary as Geikie is on the other hand an ardent advocate for the importance of fissure eruptions of basalt, particularly as explaining the Tertiary plateaus of Scotland and Oregon by comparison with Iceland, and as accounting for many ancient basalts in the geological record. "These truly 'massive eruptions'", he writes (p. 343), "have been held by Richthofen and others to represent the grand fundamental character of volcanism, ordinary volcanic cones being regarded merely as parasitic excrescences on the subterranean lava-reservoirs, very much in the relation of minor cinder-cones to their parent volcano, or of the lava-spiracles on the surface of a lava-stream"—a statement of exactly Stübel's position, and stated in a context of approval.

It should not be inferred that Geikie does not recognize the Hawaiian sink (Daly, 1911, p. 97) crater, which he calls "crater-pit" following Dana, and finds illustrated in Iceland as well as Hawaii. He accepts subsidence for the Lonar Lake in the Indian peninsula, and for Crater Lake in Oregon, but only partly so, for in both cases it is assumed that a great explosion played some part in the making. Lonar Lake

> "lies in the midst of the volcanic plateau of the Deccan traps, which extend around it for hundreds of miles in nearly flat beds that slightly dip away from the lake. An almost circular depression, rather more than a mile in diameter (1.61 km.) and from 300 to 400 feet (92 to 122 metres) deep, contains at the bottom a shallow lake of bitter saline water.... Except to the north and northeast, it is encircled with a raised rim of irregularly piled blocks of basalt, identical with that of the beds through

> which the cavity has been opened. The rim never exceeds 100 feet (31 metres) and is often not more than 40 or 50 feet (12 or 15 metres) in height, and cannot contain a thousandth part of the material which once filled the crater [So far the description would apply to many of the Hawaiian sinks as described by Pickering.] .... No other evidence of volcanic discharge from this vent is to be seen. Some of the contents of the cavity may have been ejected in fine particles, which have subsequently been removed by denudation; but it seems more probable that the existence of the cavity is mainly due to subsidence after the original explosion."

The tacit assumption of an "original explosion" is remarkable. Yet piles of blocks around the rim may be broken pressure ridges as at Halemaumau. The writer recognizes the obvious fact that at the present day enormous cavities are occasionally assisted in being laid open by the destructive agency of explosion, as in Soufrière, Santa Maria, Krakatoa, and Bandaisan, and the no less obvious but less sensational truth that in Savaii, Hawaii, Iceland, the Kivu volcanoes, and probably Réunion enormous pits or sinks are formed by subsidence amid flat fields of basalt without much explosion. As in most controversial questions both sides may justly claim the truth in certain cases, and it is quite certain that the term "caldera" is a source of discord rather than of progress. It means a "Somma" or ancient crater rim of doubtful or dual origin.

Geikie's extended personal experience with ancient and modern volcanoes gives especial value to his treatment of volcanic vents, and his textbooks are a mine of information and of reference to the student of volcanology. We shall quote here his views concerning the origin of vents and fissures, dormancy, the effects of closing vents, the permanency of volcanic districts, and his classification of the volcanic structures in cone making and fissure eruption.

He comments on so-called active and extinct phases of volcanic action and points out that "in many cases it is impossible to decide whether a volcano should be called extinct or only dormant," though there is usually no question of the extinction of districts of ancient volcanoes that are pre-Tertiary. Tertiary volcanism is what is still represented by activity in most districts. "Volcanic action is apt to show itself again and again, even at vast intervals, within the same regions and over the same sites."

The sites of volcanic action may be linear along fissures of the terrestrial crust, but they are not necessarily so. While the records of new outbreaks in historic time all concern "tracts that had already been theaters of volcanic activity, and where there are still active volcanoes," yet "volcanic energy is of itself capable of drilling an orifice through the crust and forcing its way to the surface." Ancient volcanic necks are independent of visible fault lines. Löwe, Branco, and Boess have stressed the capacity of magma to rise without fissures (Geikie, p. 280).

> "An important inference may be deduced from the consideration just stated. It is obvious that in order to be able to expel an overlying column of the earth's crust the magma must have ascended to within a comparatively short distance from the surface. In the case of the innumerable small vents which can be proved to have been drilled through unfaulted rocks, this proximity of the top of the magma to the mouths of the funnels becomes strikingly apparent. And as these vents are numerous they show that in many cases volcanic action is not deep-seated, but has its source not many hundred feet below ground."

Geikie's use of "the crust," in the sense of surface continental, sedimentary, or metamorphic rocks, in the above sentences, should be noted. Volcanic action having its "source" only a few hundred feet below ground may still be volcanic action over an ancient vent in the real crust, to which the whole known geological column of sedimentary rocks and all the metamorphic rocks added are but as a film in comparison with the igneous layers within, which are the real supporters of volcanicity. The real test of volcanism under sediment is the thermal gradient under that 70 per cent of the earth surface—the sea bottom—about which geology knows nothing.

The following from Geikie is of value:

> "Volcanoes may break through any geological formation. In Auvergne, in the Miocene period, they burst through the granitic and gneissose plateau of Central France. In Lower Old Red Sandstone times, they pierced contorted Silurian rocks in Central Scotland. In late Tertiary and post-Tertiary ages, they found their way through recent soft marine strata, and formed the huge piles of Etna, Somma and Vesuvius; while in North America, during the same cycle of geological time, they flooded with lava and tuff many of the river-courses, valleys, and lakes of Nevada, Utah, Wyoming, Idaho, and adjacent territories. On the banks of the Rhine and elsewhere, they have penetrated some of the older alluvia of that river. In many instances also, newer volcanoes have appeared on the sites of older ones. In Scotland, the Carboniferous volcanoes have risen on the ruins of those of the Old Red Sandstone, those of the Permian period have broken out among the earlier Carboniferous eruptions, while the older Tertiary dykes have been injected into all these older volcanic masses. The newer *puys* of Auvergne were in some cases erupted through much older and already greatly denuded basalt-streams. Somma and Vesuvius have risen out of the great Neapolitan plain of older marine tuff, while in Central Italy newer cones have been thrown up upon the wide Roman plain of more ancient volcanic debris. According to Professor G. Pozzi, the principal volcanic outbursts of Italy are of the Glacial period. G. de Stefani regards those of Tuscany as partly Miocene, partly Pliocene and post-Pliocene (Geikie, p. 281). The vast Snake River lava-fields of Idaho overlie denuded masses of earlier trachytic lavas, and similar proofs of a long succession of intermittent and widely separated volcanic outbursts can be traced northwards into the Yellowstone basin."

These remarks about penetration, from Geikie, suggest possibility of experiment that has not been tried. If drilling without fracture, a conception from geologic history rather than observation of process, has really occurred, then magmatic drilling might be tried on rock slabs in the laboratory with the aid of high-temperature gas inflation. Like the coefficients of expansion, conductivity, and elasticity, such a "drillable" characteristic of standard rocks might have some value. It seems likely, however, that a coefficient of magmatic penetrability would depend on heat cracking and jointing rather than on mineral texture. Rock samples differ from formations in assumption of physical properties.

By the mechanism of fissuring and intrusion Geikie develops some interesting suggestions of rhythm in cone making. Pressure of gases and the lava column

> "may act simultaneously, and their united effort has been to uplift enormous superincumbent masses of solid rock and to produce a widespread series of long and continuous fissures reaching from unknown depths to various distances from the surface and even opening up sometimes on the surface. . . . The permanent separation of the walls of fissures by the consolidation of the lava that rises in them as dykes must widen the dimensions of a cone . . . . There can be little doubt that in the architecture of a volcano, dykes must act the part of huge beams and girders, binding the loose tuffs and intercalated lavas together, and strengthening the cone against the effects of subsequent convulsions.
>
> "From this point of view, an explanation suggests itself of the observed alternations in the character of a volcano's eruptions. These alternations may depend in great measure upon the relations between the height of the cone, on the one hand, and the strength of its sides on the other. When the sides have been well braced together by interlacing dykes, and further thickened by the spread of volcanic materials all over their slopes, they may resist the effects of explosion and of the pressure of the ascending lava column. In this case, the volcano may find relief only from its summit; and if the lava flows forth, it will do so from the top of the cone. As the cone increases in elevation, however, the pressure from within upon its sides augments. Eventually egress is once more established on the flanks by means of fissures, and a new series of lava streams is poured out over the lower slopes (Geikie, p. 288). . . .

> "As the mountain increases in height (Geikie, p. 331), the number of lava currents from its summit will usually decrease. Indeed, the taller a volcanic cone grows, the less frequently as a rule does it erupt. The lofty volcanoes of the Andes have each seldom been more than once in eruption (?) during a century. The peak of Teneriffe was three times active during 370 years prior to 1798. The earlier efforts of a volcano tend to increase its height, as well as its breadth; the later eruptions chiefly augment the breadth, and are often apt to diminish the height by blowing away the upper part of the cone. The formation of fissures and the consequent intrusion of a network of lava-dykes tend to bind the framework of the volcano and strengthen it against subsequent explosions. In this way, a kind of oscillation is established in the form of the cone, periods of crater-eruptions being succeeded by others when the emissions take place only laterally."

This analysis of course applies only to a composite cone like Vesuvius. In a dome of very liquid lava like Mauna Loa, the earlier efforts of the magma would chiefly increase breadth, and the later ones height, particularly if there were increase of viscosity due to internal cooling owing to delayed emission and smaller vents. It is evident, by comparison of this with the above explanations of cone building by Judd and Dana, that the rhythms which may be established are not simple ones and that the mathematics of the volcanic cone involves many unknown and variable quantities (Becker, 1885; 1901).

A volcanic chimney becomes closed through a plugging of the vent

> "by the ascent and consolidation of solid material in it, while yet the eruptive energy of the volcano, though diminishing, has not ceased. A time is reached when the ascending magma, impelled by pressure from below, can no longer overcome the resistance of the column of solid lava or compacted agglomerate which has sealed up the orifice of discharge, or at least when it can more easily force a passage for itself between the sedimentary strata on which the whole volcanic pile may rest, or between the lava-sheets at the base of the pile, or into fissures in either or both of these groups."

Such intrusions are so marked a feature of eroded volcanic regions that they "must be regarded as marking an ordinary phase of volcanic action." In other cases intrusions may indicate that "plutonic forces have not succeeded in establishing a connection with the surface. . . . These uncompleted efforts to form volcanoes have given rise to dykes, veins, bosses, sills and laccoliths" (Geikie, p. 313). This doctrine teaches (1) the conquest of a waning volcanicity by the weight and strength of its own deposits, and (2) the dependence of effective intrusion on thwarted extrusion. Both cases imply a sedimentary and volcanic pellicle over the globe beneath which volcanism as a force is partially confined. Diagrams that show flank lava flow from craters escaping through sills rather than dikes should be suspected of error.

Geikie classifies volcanic structures into two large groups, cones and fissure eruptions, as follows:

1. a. Volcanic cones
        1. Explosion craters, crater lakes
        2. Cones of nonvolcanic materials
        3. Tuff cones, cinder cones
        4. Mud cones
        5. Lava cones
        6. Cones of tuff and lava
    b. Submarine volcanoes
2. Fissure (massive) eruptions

This classification calls for no extended discussion and contains no suggestion of a genetic series. The inclination of the lower lava beds of an eruption center, and particularly of such an outlier as Monte Somma, led to the famous theory of "Elevation Craters" of Leopold von Buch, whereby it was supposed that strata were domed like a laccolith to make a volcano, which erupted through the apex of the blister. The notion was supposedly disproved by Lyell and others (Geikie, p. 321):

> "The typical conical form of most volcanoes is that naturally assumed by a self-supporting mass of coherent material. It varies slightly according to the nature of the substance of the cone, the progress of atmospheric denudation, the position of the crater, the direction in which materials are ejected, the force and direction of the wind during an eruption, the growth of parasitic cones, and the collapse due to the dying out of volcanic energy."

Of submarine volcanoes Geikie (p. 341) writes:

> "In estimating the bulk of the oceanic volcanoes, we must remember the profound depths from which many of them rise. An islet which only just shows itself above sea-level must often be the summit of a cone which would be reckoned among the more colossal volcanoes of the globe if it stood on the land. Christmas Island, in the Indian Ocean, the crest of which is 1100 feet (335 metres) above the sea, is really a mountain 15500 feet high (4740 metres), rising from one of the ocean abysses. Still, more gigantic is the volcanic ridge of the Sandwich Islands, which has been built up from a depth of more than 18000 feet (5490 metres) to a height of nearly 14,000 feet (4270 metres) above sea-level, thus forming a volcanic chain higher than even the highest peak of the Himalayas, and still continuing to erupt from its crest.
>
> "Submarine eruptions.... appear to build up conical volcanoes, rather than to form wide plateaux. They tend to occur along tolerably well-marked lines, as well as in scattered groups." Along the fissure lines occur cones which "have come into existence in succession, some dying out, and others still continuing. Thus along the great volcanic ridge of the Sandwich Islands.... fifteen volcanoes of the first class have been active, but all of them, save three in Hawaii, appear to be now extinct."

These points are cited here because they bear on crater succession and crater development in such cases as Pelée, Soufrière, Kilauea, and Bogoslof, and on the general theory of terrestrial craters. But Geikie does not accent the measure of human ignorance of the sea bottom.

The accentuation of fissure eruptions of basalt by Sir Archibald Geikie in all his later writings is based upon studies of European Tertiary basalts, especially in northeast Ireland, the Inner Hebrides, and the Faroe Islands, which he traces onward to the active fissures of Iceland (Geikie, 1897). His generalizations concerning the importance of basalt plateaus as fundamental types of volcanism entirely agree with those of Stübel, but he has not, to the writer's knowledge, attempted to connect these facts with any genetic scheme or with any comparison to the moon. His treatment of the moon is brief (p. 32) and eclectic, and not in immediate connection with his chapters on volcanism, and the influence of water in volcanic action dominates his thought so that the doctrines of Arrhenius which compare volcanic eruption to that of geysers appeal to him rather than any theories of "dry fusion." There are considerable gaps left in volcano learning, after the student has read the *Textbook*, notably with reference to what were the real craters or vents which gave rise to basalt plateaus, and what part water played in those eruptions. A service was rendered geology, however, by the radical departure from the Vesuvian ideal of volcanic action which Geikie introduced, when he wrote,

> "the most gigantic displays of subterranean energy are manifested by yet another type of eruption, where lava flows out from fissures, which reach the surface, spreading sometimes over areas hundreds

of miles in extent. Such fissure-eruptions have been chiefly exhibited in historic times in Iceland. Large tracts of that island have been rent by fissures, of which two systems are specially marked, one directed from S.W. to N.E. and the other from S. to N." A fissure "becomes the scene of intense volcanic activity when lava rises in it and flows out tranquilly on either side, sometimes forming a row of cones of slag along the line of the chasm or a long rampart of slag and blocks piled up on either side.... So insignificant are these hillocks that in a rugged volcanic landscape they might not attract attention, yet they mark the source whence milliards of cubic yards (yard = .91 metre) of lava issued." The Icelandic lava is remarkably liquid and forms great deserts of two or three thousand square kilometres. "In some parts of Iceland the lava has been built up into vast flat domes like those of Hawaii having a gentle inclination in every direction. The highest of these are 1209 and 1491 metres high by from 6 to 15 kilometres in diameter. An elliptical crater on the loftiest dome measures 1100 by 380 metres.... The mountain Hekla (4961 feet, 1513 metres) ... is made up of successive sheets of lava and tuff, which, however, have not been formed into a cone but into an oblong ridge, fissured in the direction of its length and bearing a row of craters along the fissures."

"The most stupendous example of this type of volcanic structure occurs in Western North America, ... estimated to cover a larger area than France and Great Britain combined. The Snake River plain in Idaho forms part of this lava flood.... Looked at from any point on its surface, it appears as a vast level plain like that of a lake-bottom, though more detailed examination may detect a slope in one or more directions, and may thereby obtain evidence as to the sites of the chief openings from which the basalt was poured forth.... There are no great cones whence this enormous flood of basalt could have flowed. It probably escaped from orifices or fissures still concealed under the sheets which issued from them, the points of escape being marked only by such low domes as could readily be buried under the succeeding eruptions from other vents.[11] That it was not the result of one sudden outpouring of rock is shown by the distinct bedding of the basalt, which is well marked along the river ravines. It arose from what may have been on the whole, a continuous, though locally intermittent, welling-out of lava, probably from vents on many fissures extending over a wide tract of Western America during a late Tertiary period, if, indeed, the last eruptions of this vast region did not come within the time of the human occupation of the continent. The discharge of lava continued until the previous topography was buried under some 2000 feet (610 metres), (but in places as much as 3700 feet [1128 metres]) of lava, only the higher summits still projecting above the volcanic flood.[12] At a few points on the plain and on its northern margin, the author observed some small cinder-cones. These were evidently formed during the closing stages of volcanic action."

This description might be that of a traveler returned from riding across a lunar mare. The assumption of mutually obliterated fissures, comparable to the Laki fissure in Iceland, hardly seems justified. All the comparisons made are with the Hawaiian broad dome and pit vent type of accumulation, pit vents which might readily obliterate themselves, given a somewhat greater liquidity of lava and a basin topography to be filled, rather than a dome to be built. There are recent reports of the Water Supply Branch, U. S. Geological Survey, elucidating the volcanic mechanism of the Snake River and Columbia plateaus.

In concluding this review of Geikie on volcanic vents, he gave a fair expression of the nineteenth century view concerning the distribution of vents areally and in time. He shows that active vents

(1) Occur along the margins of ocean basins.
(2) Follow dominant mountain ranges.
(3) Rise from submarine ridges.
(4) Are generally near the sea or an inland lake.
(Exceptions are in Manchuria and central Asia.)
(5) Follow lines, probably of fracture or plication.
(6) On a smaller scale occur in groups.

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[11] "Captain Dutton has remarked the absence of any conspicuous feature at the sources from which some of the largest lava-streams of Hawaii have issued."

[12] Professor J. LeConte believed that the chief fissures opened in the Cascade and Blue Mountain Ranges (Geikie, p. 345).

With reference to the records of the ages,

"within the same comparatively limited geographical space, volcanic action has been rife at intervals during a long succession of geological ages. Even round the sites of still active vents, traces of far older eruptions may be detected, as in the case of the existing active volcanoes of Iceland, which rise from amid Tertiary lavas and tuffs. Volcanic action, which now manifests itself so conspicuously along certain lines, seems to have continued in that linear development for protracted periods of time. The actual vents have changed, dying in one place and breaking out in another, yet keeping on the whole along the same tracts. Taking all the manifestations of volcanic action together, both modern and ancient, we see that the subterranean forces have operated along great lines in the earth's crust, that they have again and again been active over regions which now lie far within the borders of the great continents, that the existing volcanoes form but a small proportion of the total number which have once flourished, and that certain regions, like most of European Russia, furnish no evidence of ever having possessed active volcanoes within their bounds."

N. S. SHALER 1903

Shaler, Stübel and Pickering all believed, like Suess, in comparison of earth and moon:

"The most notable feature on the lunar surface" wrote Shaler (1903), "is the existence of exceedingly numerous pits, generally with ring-like walls about them, which slope very steeply to a central cavity and more gently towards the surrounding country. These pits vary greatly in size; the largest are more than a hundred miles in diameter, while the smallest discernible are less than a half-mile across. The number increases as the size diminishes; there are many thousands of them, so small that they are revealed only when sought for with the most powerful telescope and with the best seeing. In all these pits, except those of the smallest size, and possibly in these also, there is within the ring-wall and at a considerable though variable depth below its summit a nearly flat floor, which often has a central pit of small size or in its place a steep rude cone. When this plain is more than twenty miles in diameter, and with increasing numbers as the floor is wider, there are generally other irregularly scattered pits and cones. . . . On the interior of the ring-walls of the pits over ten miles in diameter there are usually more or less distinct terraces, which suggest, if they do not clearly indicate, that the material now forming the solid floors they enclose was once fluid and stood at greater heights in the pit than that at which it became permanently frozen. [Could not the terraces be marginal downslips? (Pl. 45 b, veneer, 48 b, downslip)] It is, indeed, tolerably certain that the last movement of this material of the floors was one of interrupted subsidence from an originally greater elevation on the outside of the ring-wall, which is commonly of irregular height with many peaks. There are sometimes tongues or protrusions of the substance which forms the ring, as if it had flowed a short distance and then had cooled with steep slopes."

"The evidence from the intersections clearly shows that the greater of these structures (volcanoids) are prevailingly the elder, and that in general the smallest were the latest formed. In other words, whatever was the nature of the action involved in the production of these curious structures, its energy diminished [Did the energy diminish or the crust thicken?] with time, until in the end it could no longer break the crust. In the region outside of the maria much of the general surface of the moon between the numerous crater-like openings appears in the best seeing with powerful telescopes to be beset with minute pits, often so close together that their limits are so far confused that it appears as honeycombed."

"The volcanoids of larger size which are arranged in linear order are not numerous. We find the instances of such arrangement becoming more numerous as the structures are of smaller diameter. When, in following down the series of volcanoids as regards size, we come to the pits less than a mile in diameter, those commonly termed craterlets, we note that the linear order, hitherto exceptional, becomes so common that the exceptions are rather to be found in the departures from it. The observations of W. H. Pickering and others, make it evident that there is a causal relation between the smaller visible pits and the cracks that form on the surface of the moon. There can be no question that there are thousands of these smaller of the craterlets which are thus disposed in lines, some of the series extending for hundreds of miles."

By this analysis Professor Shaler concludes that as lunar craters become smaller they become progressively younger and more aligned. We get thus in the lunar history, first, isolated, large volcanoids, where large-scale foundering of a thin shell was easy, then crustal thickening and some linear control of craters by cracks, and finally craterlets prevailingly along fissures in a thickened crust which did not permit extrusion except by cracking. The maria, however, according to this author, were younger than the large volcanoids, as shown by the melting down or burial of the latter by the lava floods of the maria, and cannot be classed as the oldest and largest volcanoidal forms in the series, though they have a circular tendency in some instances.

Shaler cites classified lunar volcanic vents as:

Walled plains
Mountain rings
Ring plains
Craters
Crater cones
Craterlets
Crater pits
Depressions

Walled plains include the greater pits with the ring of high land about them. Generally there is no great difference in level between the outside and the inside of the walled plain, but there are many exceptions to this. There are frequent irregularities, clefts, and breaks in the walls, and some minor craters, cones, and ridges on the floor and rims, so that they are essentially like the mountain rings, except for certain accidents which have befallen the members of the last-named group.

The mountain rings lie in the maria. They are largely ruined remnants of walled plains, partly "melted down" or drowned by the marine floods of lava. Shaler rejects this group on the principle that state of obliteration is not a basis for classification.

Ring plains are strongly walled volcanoid pits with continuous ramparts, steep inner declivity, and frequently terraced inner slopes. They have better defined cones than the wall plains.

Craters are distinct pits 3 to 15 miles in diameter, very numerous on the moon, widely distributed, occurring even on the walls of the larger structures, and hence usually newer than the wall plains or ring plains. Structurally they are similar to the larger volcanoids.

Crater cones are all small, with pits generally less than a mile in diameter, without distinct floors, sometimes with rounded bottoms, "as if there had been lava in the cups, which had withdrawn with the cessation of activity into the deeper part of the crust."

The craterlets or crater pits are the smallest observable vents. There are many thousands of them on the moon. Characteristically there is no distinct wall or cone, the opening often being abrupt, "as if it were brought about by a mere subsidence of the area in which it lies." In some cases there are traces of a ring wall, and frequently the pits are not circular but irregular. Frequently craterlets lie upon ridges.

Depressions so-called are ill-defined hollows not properly belonging to any of the other groups. There are also "crater valleys," in which one or more craters have been deformed so as to make a broad valley. The moon also shows clefts, or elongated straight-sided and often terminally walled valleys believed to be graben or multiple-fault depressions, and rills, which are open rifts of all sizes frequently with craterlets along their courses. There are some rare fault scarps on the moon.

A. STÜBEL 1903

Stübel suggested that volcanoes frequently exhibit distinct stages of renewal of activity and classified domes, cones, and craters. Baron von Stübel's contributions to the published records of terrestrial volcanism have been voluminous, and the Grassi Museum in Leipzig contains admirable collections illustrating his tireless efforts in the mountainous volcanic fields of Bolivia, Peru, Ecuador (1897), and Colombia (1906). As geologist, artist and philosopher he unremittingly devoted his life to the study of the theory of volcanism, and his field experience impressed upon him, in those regions where volcanoes are greatest, the relatively ephemeral character of modern volcanic activity in contrast to the colossal outpourings of ancient days. Stübel's contributions to volcanology have been of two kinds—facts of observation and a deduced hypothesis of volcanic action. In this chapter we consider those facts which he grouped into generalizations, whereby he built up a classification of volcanic structures based on principles of genesis.

Fundamental with Stübel is the principle that every volcanic orifice has the task of relieving of lava, at certain times, some sort of an underground chamber or conduit. He holds that "the distinctive and normal form of deposit of molten magma is by spreading out in flows" and all heaping up of eruptive material into mountains or hills is relatively subordinate and decadent.

"A mountain, among eruption products, signifies always the dying productiveness of a reservoir, whether through increase of dead fragmental matter, or through diminished lava supply accompanied by decrease in fluidity. Craters of large-scale mountainous volcanoes, instead of marking the site of eternal constructive energy, mark rather the place of sudden withdrawal of lavas which sank back into the depths before their complete solidification and left exposed on the surface broad basins of most varied outline."

This does not mean that the crater is the basin in question, but that cone and crater are built above such a basin; the original orifice, of lava outpouring and lava subsidence, is kept open to pile up a cone in the ages of decadence which follow the first great age of lava floods. The understructure of that first age is called "monogenic," meaning "made at one time" or by one eruptive process; the superstructure is called by contrast "polygenic," made by successive various heapings of lava and ash.

This distinction, based on comparative studies of volcanoes in many districts, is a most important contribution to volcanology, which cannot be ignored, whatever may be its meaning. It is based on a group of facts noted in many lands and on the moon. Probably all terrestrial volcanoes have a substructure of lava, and the cinder cones of present-day activity surmount it. This leads to the recognition of a succession of types of volcanic outpouring—the broad plain, the "caldera" where a rim encircles a field whence lava has subsided through the original conduit, the dome, and the cone. Stübel writes,

"among all volcanic structures the so-called "Caldera mountain" must take first place. Its genetic importance especially in combination with a younger eruption cone, has been fully acknowledged by geologists of the old and the new generation, but nevertheless, its origin has been a subject of incessant discussion without any result. Nothing has more regrettably hindered orderly and definite progress in volcanologic research than the "caldera" question from the time when it was first broached to the present day."

Stübel defines caldera as a

"great, more or less cone-shaped crater-mountain, the crateral depression of which has so great a diameter in comparison with the height and outer circumference of the circular or sub-circular mountain ridge, that the latter cannot be explained as the gradual heaping up of materials from so relatively great a crater and a proportionately wide conduit; also the tectonic relations of the annular wall deny such origin."

The caldera also has a steep infacing wall showing bedding, and according to Stübel's view is not an explosion pit but a sink due to engulfment (*Einsturzkrater*). The bedding in the wall is usually of very flat centrifugal dip, and the materials either lava or slaggy breccia,[13] not usually ash. The typical monogenic ancient eruption center of Stübel is a caldera, and within it or upon it, centrally or excentrically, the later eruptive cones of second or multiple generation (composite or polygenic cones) may be built by a revival of the ancient vent. Monte Somma, the ancient annular ridge of Vesuvius, is the type caldera of engulfment consisting of slaggy agglomerates (aa lava flows?) and lavas cut by many dikes. It is well known that hundreds of other volcanoes have Sommas marking the periphery of craters vastly greater than the craters of the present day, and the attempt to explain these great rings on a strictly uniformitarian basis has always been difficult. Stübel believes that places of volcanic activity contain an orderly group of superposed topographies, beginning with plateau flows, domes, and calderas, and ending with composite cones and cinder cones. His experience among the deeply dissected great volcanoes of the Andes justified this, and probably nowhere else on earth is the understructure of active volcanoes better exposed. He believes in lunar analogies and in the lunar ring volcanoid as the type caldera.

In the memoir cited (1903) the reader will find a summary of Baron Stübel's classification of volcanoes and of his theoretical work, the book putting the author's final results into compact form, while at the same time including a commentary on the published descriptions of the eruptions of 1902 in the Caribbee Islands.

He proposes that the expressions volcano, volcanic mountain, and eruption center be clearly distinguished:

A volcano is a mountain built by eruptive activity in many separate eruptions, these being in relatively rapid succession but separated by pauses of varying duration; its activity is not wholly closed. Kilauea is a volcano.

A volcanic mountain is a mountain mass of monogenic volcanic origin; it never appears to have had a continuous eruptive history in the sense of a volcano. Mauna Kea is a volcanic mountain.

An eruption center is a monogenic structure in or about which eruptive activity has been renewed after one or more intervals; it is a more inclusive term than volcano or volcanic mountain and implies ordinarily a place of active volcanism rather than a single topographic feature. The island of Hawaii is an eruption center. (We here extend this to *Volcanic System*, the whole Hawaiian ridge.) Stübel's classification of volcanic piles is given in Table 3.

It should be observed that Stübel's experience is entirely continental and that the possibly more important ocean floors, although areally greater, are unknown to him.

The terms "active volcano" and "second period" used in this table are ambiguous and partly inconsistent, for in the text Stübel condemns the use of "active volcano" as an outworn indefinite and scientifically untenable expression—hence his proposal of "volcano," "volcanic mountain," and "eruption center." A "second period" for earthly volcanoes which are today in activity, and in such diverse activity as

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[13] Agglomerate in many old writings is aa basaltic lava, not explosive in origin.

TABLE 3.—*Stübel's classification of craters*

A. Monogenic domes and their transition-forms to cones, sometimes compounded with younger structures.
  1. Simple domes.
    I. Chimborazo Type, gradual development of a simple dome in one period.
    (Ecuador)
    II. Pachachata Type, transition from dome to cone in one period.
    (Peru-Bolivia)
    III. Quilindana Type, simple dome followed by summit lava peak in one period.
    (Ecuador)
    IV. Bohemian Type, formation of a group of lava domes (or cones) in one long period.
    (Bohemia and Saxony)
    V. Sajama Type, high pyramidal cone on a flat understructure.
    (Peru-Bolivia)
  2. Domes with younger additions.
   a. By revival of old vent.
    VI. Sangay Type, dome transformed in second period into an active cone.
    (Ecuador)
    VII. Cumbal Type, activity of second period limited to great central or lateral lava streams.
    (Colombia)
   b. By opening new side vent.
    VIII. Pichincha Type, of two domes side by side formed in first period, only one remains active in second period.
    (Ecuador)
    IX. Ararat Type, great dome in first period, smaller cone beside it in second.
    (Persia)

B. Monogenic Calderas, usually compounded with younger structures.
  1. Simple caldera
    X. Rumiñahui Type, gradual development of a caldera in one period.
    (Ecuador)
  2. Calderas with younger additions.
   a. By revival of old vent and transition to an active volcano.
    XI. Somma-Vesuvius Type, caldera in first period, eruption cone within it in second.
    (Italy)
    XII. Etna Type, caldera in first period, eruption cone on its rim in second.
    (Italy)
    XIII. Cotopaxi Type, extensive eruption center of several cones in first period closed with caldera engulfment: buried partially by central high cone in second period.
    (Ecuador)
   b. By revival of old vent without transition to an active volcano.
    XIV. Monti Laziali Type, wide ring caldera in first period, followed in second period by inner concentric ring and final inner pinnacle.
    (Italy)
   c. By opening new side vent.
    XV. Imbabura Type, dome surmounted by steep cone around lateral caldera in first period; smaller cone beside it in second.
    (Ecuador)

Mauna Loa and Fujiyama, for example, the former possibly true "monogenic" eruption, is a wholly indefinite thing. A "first period"—within uncertain time limits—is conceivable; but in the discussion of revival of the vent, thereafter with "polygenic" decadence, and many eruptions going through some sort of progression in quality, intervals and products, we are hardly justified in speaking of all the time up to the present as the "second period." Secondary it all may be in the sense of subordinate to the first monogenic mass, but not second in any sense, when innumerable eruptions or eruptive epochs are involved. In most eruption centers of the world, the Miocene was the time of "first period" and probably was so in Hawaii.

With regard to the "eruption center," there should also be provision for eruption fissures or lines. This is vigorously disputed by Stübel, who, influenced largely by the continental volcano groups, insists that "it remains for the defenders of the fissure hypothesis to fortify their theory with new and powerful proofs (p. 34)." After expressing doubt of the fissure explanation of the linear arrangement of volcanoes, he says

> "we believe that this doubt is fortified by an examination of the surface of the moon, crowded with volcanoes, in many places uniformly dotted over the surface wholly without order: . . . . the smaller crowded volcanoes of the moon are vastly larger in size than the average of the earth. What then can fissures signify?"

But perhaps Stübel did not know of Shaler's observation that as lunar volcanoids grow smaller and more numerous "the linear order, hitherto exceptional, becomes so common that the exceptions" are rather those which do not occur in lines. That is, lunar volcanoes become almost exclusively linear in arrangement as they approach in size those of the earth, and the unexplained bright lines are linear for enormous lengths. This is properly attributed to crustal thickening and linear cracking, and moreover there is not the slightest doubt but that cones occur along fissures in Iceland, along eruption cracks on Etna, Hekla, Mauna Loa, Hualalai, and Kilauea, along rills (fissures) on the moon, along circumferential cracks on the terracelike rims of the great lunar ring craters, and even along the edge of subcircular maria. If volcanic vents did not occur in lines along fissures, our earth and the moon would violate the mechanics of ordinary fracture. As the innumerable dikes of the subsurface zone of volcanism indicate, linear fracture is common. It is a question not of hypothesis but of facts.

Type III of Stübel's table, and probably Types II, V, and XV, volcanoes crowned with steep lava peaks, and often without present-day craters, are among the distinctive contributions of Stübel's field work. In this connection Geikie writes (p. 322)

> "Among the Andes another type than that of the normal cone has been developed. Huge masses of lava have there been built up into domes and pinnacled rocky isolated mountains, having a singular diversity of external form combined with a comparative simplicity of internal structure. Dr. Stübel, who has so sedulously studied the volcanoes of Ecuador, has announced his conviction, as the chief result of his study, that the majority of them have been formed, each as essentially the product of one single outbreak and not of a long series of widely separated eruptions."

The central steep peak as the last protrusion from the depths of a viscid magma was, in some of Stübel's recorded and figured types, undoubtedly prophetic of the cumulo-volcano made famous by the spine on Pelée and the later discovery of similar erections on Bogoslof, Tarumai, Usu, and Santa Maria, and the probable identification with it of the earlier-recorded Georgio I at Santorin, Fuego in Guatemala, and many other lava domes, cones, and pinnacles crowning volcanoes which sometimes are craterless. Rising crater plugs are common in the Dutch East Indies.

E. SUESS 1906

Edouard Suess asks a question of great importance in considering permanent volcanic tracts and regions supposed never to have possessed active volcanoes:

Are there any nonvolcanic areas on earth? The oldest places that suffered in Archean times what Suess calls "rigefaction", and are characterized by crystalline gneisses or broad undisturbed marine deposits overlying Archean, are commonly classed as nonvolcanic, but the presence of batholithic plutonic rocks within their borders would make such classification questionable.

In making comparisons between earth and moon, Suess (English edition, 1906, vol. IV, p. 587, 601) accounts for the lunar maria as due to foundering over batholiths and accounts for the marine group of volcanoes on the earth by a similar extrusion from batholithic roofs through a network of fissures.

> "It is well known that the majority of oceanic islands are of volcanic origin. In any case, the distribution of recent volcanoes over the bottom of the oceans contrasts with their absence in India, Cambodia, the North China mole, Angara land, Laurentia, and Brazil, and also with their rare occurrence in all ancient lands, excepting Africa, where they arise in a different manner."

In another sentence (p. 587) Suess includes Australia among the nonvolcanic lands. One might add the Russian platform referred to by Geikie, the Baltic shield, and perhaps, in the light of Scott's, Shackleton's, Mawson's, and Byrd's discoveries, a great gneissic tract in central Antarctica. If, however, there is any justification for attributing to subcrustal batholiths the volcanoes of the seafloor, much more must the solidified batholiths, Sial and Sima, granite and anorthosite, which characterize the old lands of the globe, be attributable to volcanic energy which manifested itself in those places. No one familiar with the weathering and metamorphism of diabase would expect extensive preservation of the lava plateaus of those ancient days. Their conduits, filled with their differentiates and assimilates, are expectable, and the expectation is justified by the facts. It would thus appear probable that Geikie's generalization may safely be extended as follows:

Taking modern and ancient volcanic action together, the subterranean forces have operated along lines, the ignisepta through the crust, and at points or groups of points in the earth's crust, from the most primitive times to the present day. Existing volcanoes form a remnant active in regions which have always been volcanic, though there have been shiftings of the actual vents and intervals of sedimentation and intrusion over the continents. The Archean districts of the earth, devoid of active volcanoes, are those places where the extrusion earliest came to an end. Volcanic action was once the dominant process over the whole earth.

The deeper afferent paths by which magma rises to volcanoes Suess believes to be generally fissures (IV, 569). In both the Atlantic and Pacific regions he finds examples of (1) diffuse volcanic areas, or basaltic sheet floods; (2) volcanoes standing on disjunctive lines, the linear troughs and volcanic arcs; and (3) volcanoes collected in groups as in the Azores and Galapagos Islands, but here, too, isolated lines attest the existence of fissures.

With reference to volcanic vents, Suess makes the following important comparisons of earth and moon. He believes that direct melting down—*i.e.*, complete absorption of the roof—is the lunar form of volcanic action. He calls the maria and crater rings "smelting furnaces."

> "The terrestrial batholiths show us how a heated mass in the interior of the earth may, if the heat is continually renewed, approach the surface by melting its way up. If it reaches the surface, then

> as we see in the moon, a lava plain is formed, the outline of which, owing to the comparatively small diameter of our satellite, must approximate to a conic section,"

or better, a spheric section. The maria, according to Suess, are insunken plains of lava "with a regular round or oval outline", sometimes overflowing neighboring depressions. The irregular maria are occasioned by the crowding of confluent circles. Typical cases are the ellipse of the Mare Crisium, with diameters of 570 and 450 kilometers, and the Sinus Iridum (215 kilometers), which opens into the Mare Imbrium. "Where two contours intersect, wedge-shaped horsts are formed." The capes at the opening of Iridum, and the Apennines and Carpathians, are examples of such horsts. The circular ramparts of the walled plains and ring plains are believed to enclose smaller smelting furnaces, with Clavius a large example, 228 kilometers across.

> "At the bottom lies a consolidated lava lake; frequently the first subsidence has been followed by a second, third, sometimes a fourth, and exceptionally even by a fifth. The lake sinks deeper and deeper, almost always becoming smaller at each descending stage, and at the last, when it has become smallest, it may lie more than 5000 metres beneath the surrounding surface."

A type of crater of great interest to the student of crater genesis Suess calls "riding craters"—younger vents with their accumulations, seated on the margin of a large one, hence riding on the edge. They are known in the Phlegraean fields, at the lakes of Bolsena and Bracciano, and they are common along the caldron fractures which separate the subsided terrace blocks on the periphery of the lunar rings. The "riding" on the ancient rampart (IV-595) may perhaps be explained by the fact that in the ancient crater, on the margin of the obstruction or plug next the inner side of the rampart, peripheral fissuring frequently occurs; out of the fissures gases ascend. This is beautifully exemplified in the Phlegraean solfatara. The outrushing gas bores a way for itself, and a new crater is formed. From these smaller peripheral apertures, according to Loewy and Puiseux, proceed the long rays of the white ash which surround many of the lunar craters. This is why some of these rays are not radial, but tangential, with regard to the crater. From Meissier two slightly divergent tangential lines proceed, which were probably produced by the same ash cyclone. It has been shown, in particular, that the rays proceeding from Tycho exhibit a denser whiteness where they encounter an obstacle and that in general lines of this kind flatten out upon plains. Consistent with this Sapper observed in the eruption of Santa Maria in Guatemala, October 1902, that "the slopes facing the volcano were more thickly covered with ash than those facing away from it." (Loewy and Puiseux, *Atlas of the moon*, Paris, III 37, VII 17, VIII 14.)

Suess cites Loewy and Puiseux as describing Cichus as a cinder cone, in addition to the one described below by Pickering. He makes more of gas explosions, ash, and pulverization on the moon than other authors. The long "ash" lines may be solfatarized belts. Hyginus is compared to Tarawera, and the pits aligned along lunar rills are compared to the Icelandic fissures. "They are related to the smelting furnaces somewhat in the same way as the long straight fissures of Iceland, with their rows of pits and craters, are related to the caldron of Askya." The lunar bowls with sharply defined margin, great depth, diameters up to 18 kilometers, and some conical elevation, of which Ptolemaeus A is the type, Suess (1906, IV, p. 596) regards as formed

> "by isolated explosions of gas.... Whatever other physical differences distinguish the earth and the moon they agree in the fact that the volcanic activity on both has passed through a very similar course of development. Considering how close a correspondence exists the question arises whether the terrestrial sediments do not conceal some sort of substructure which may have been formed in the course of time in the same manner as the lunar surface, and may have influenced or even controlled all the tectonic features of the earth."

W. H. PICKERING 1906

W. H. Pickering has compared Hawaiian and lunar craters. He cites three types of terrestrial vents

> "according to the materials of which they are composed. These are (a) tuff or tufa cones, which are made of hardened volcanic mud, (b) cinder cones, made of scoria, lapilli, or sand, that is, lava broken up into masses of varying size, by the action of steam, from stones several inches or even feet in diameter to fine powder, and (c) lava craters, where the lava occurs in unbroken masses". This third class "most resembles what we find on the moon".

After pointing out that all classes of craters are found in Hawaii, Pickering subdivides the lava structures into cones, pits, rings, and bowls.

"Although sometimes of small size, the lava cones often emit vast volumes of lava, which taking the form of broad streams may extend for many miles." Etna and Mauna Loa are cited as examples on earth, and a small unnamed cone between Kies and Mercator as a lunar one closely comparable to such a volcano as Etna. It is 610 meters in height, 15 kilometers in diameter, contains a summit crater less than 1 kilometer in diameter, and has a mean outer angle of slope of 4.8°. It is revealed by one of Professor Ritchey's remarkable photographs taken at the Yerkes Observatory.

> "The lava pits are by far the most numerous group (in Hawaii). They have no outer slopes whatever, consisting simply of a pit sunk in the ground. Their walls are sometimes vertical, descending without talus to a flat floor; sometimes the talus is present, and may cover the whole floor, leaving the bottom as a conical pit. Sometimes the walls are inclined, descending at a uniform slope to a flat floor. The slope in this case is usually steep,—perhaps 45°."

Pickering considers the lava pits "true engulfment craters", as distinguished from expulsion craters which make cones and flows. They are very minute objects on the moon; "no large crater pits are known". The earthly examples are the well-known active craters of Hawaii, Kilauea and its inner pit Halemaumau, Mokuaweoweo on Mauna Loa, and numerous coneless engulfment craters on the slopes of Hualalai.

Lava rings are rarely preserved in Hawaii, "and resemble the larger craters found upon the moon. They have flat floors and sloping inner and outer walls." They have formed again and again as solidified ramparts about circular pools of lava in Kilauea (Pls. 9, 10) but they cave in and are destroyed when the lava sinks away into the depths. There are ancient rings preserved on Hualalai and Mauna Loa. Schickard, Phocylides, Clavius, and Wargentin are cited as crater rings of various depths on the moon, with diameters from 87 to 219 kilometers and depths up to 4 kilometers. The proportion of depth to diameter is much less in the lunar rings than in the small Hawaiian ones, and the greater proportional depth of the latter is believed to account for their usual destruction by caving.

> "On the Moon no crater is known whose depth exceeds five miles (8 km.), and two miles (3.22 km.) is the usual depth for large craters. This distance compared to a diameter of twenty (32 km.) to sixty (97 km.) miles is so slight that the ring remains uninjured. The smallest crater rings are about five miles (8 km.) in diameter."

"The lava rings frequently have on their floors central peaks and pits. Lava bowls differ from lava rings

> "in that the bottom instead of presenting a well-defined flattened floor is concave, the curvature being continuous with that of the walls. With the exception of the crater pits, nearly all the smaller depressions upon the Moon are crater bowls, and they outnumber at least ten times all the other depressions put together. One of the largest and best situated crater bowls is Triesnecker, 14 miles in diameter. It has an inconspicuous central peak. In the smaller bowls this feature seems to be lacking. A well-graduated series of bowls is shown in the interior of Clavius."

Pickering considers that decrepitation due to extremes of temperature, a range of 300°C. every fortnight, would destroy ridges and fill hollows in small craters sufficiently on the moon to produce with talus the bowl curvature. Lava bowls are illustrated in Hawaii by the third of the Puna chain of craters, Aloi, and pits on Hualalai.

Pickering further distinguishes among minor features spiracles, pinnacles, caves, channels, and ridges. Spiracles are built by the ejection of blobs of lava vertically through blowholes by escaping gases, so as to pile up a hollow cone. Pinnacles are slabs of old lava, piled up in horizontal layers by more recent flows, or huge blocks fallen from cliffs or half engulfed in liquid lava which has frozen about them. Caves are "due to the fact that the surface of the lava hardens first, and that the lower portions meanwhile flow away, leaving a cavity." Sometimes lava channels form in the same manner without any roof. Ridges are formed by a new lava pushing its way like a gigantic mole through and under an old shell so as to elevate and fracture the crust along a sinuous line, making a distinct ridge.

The selenographer's classification of craters is more satisfactory and complete than that of the geologist. The actual volcanic vent in the earth crust is almost unknown to the geologist, who has classified the conduits below, from erosion sections, and the constructional cones above, but has never seen a new volcano break out on nonvolcanic soil. The "new" volcanoes of history—Monte Nuovo, Thera, Graham Island, Jorullo, Bogoslof, Paricutin, and the like—are either the summit revivals of submarine volcanoes or merely new local heapings of lava or debris in ancient volcanic fields. There is no proof in any case on earth known to the writer of the spontaneous opening of an active volcano vent in a region where surface igneous rocks are unknown. Evidently local volcanic activity of the present day is inherited from earlier ages.

G. MERCALLI 1907

The late honored Director of the Royal Vesuvian Observatory, Professor G. Mercalli, who devoted an energetic life to the study of the Italian volcanoes, has written a thorough treatise (1907) on the active volcanoes of the earth, based on extended personal field experience. Mercalli distinguishes morphologically the fissure, submarine, Vesuvian, and puy types of volcanoes, including under "Vesuvian" all the central eruption domes and cones of continuous or intermittent activity, whereas the "puys" are small clustered or isolated products each of a single effort. Fissure eruptions are divided into the explosive (Tarawera) and effusive (Iceland) types. Central eruptions (Vesuvian) produce lava volcanoes, mixed volcanoes, and tuff volcanoes. These are discussed under the headings lava cones (Hawaii), extrusion cones (cumulo-volcano) as at Pelée or Santorin, domes of intumescence, made by upheaval of lava crusts over a lava flow which has penetrated old layers, cones of blocks (Merapi, similar to cumulo domes), and mixed cones. Mercalli notes the great diversity of cone profiles and draws the important conclusions (which Suess, 1906, vol. IV, p. 594, and some other writers have overlooked) that (1) the slope of a lava cone is a function of the fluidity of the magma, and (2) the profile of cones of projection depends not only on the nature, but also on the physical condition, of the materials ejected.

Craters and vents are critically classified by Mercalli. A crater has rim, wall, and floor, and the floor may be perforated by one or more vents (bocca). Craters are terminal or lateral and are products of explosion, engulfment, accumulation, and mixed origin.

(1) Craters of explosion are occasioned when a mountain is eviscerated by a stupendous expulsion of vapor or gas; examples, Bandaisan in 1888 and Sumbawa in 1815 (Tambora).

(2) Craters of engulfment are formed when, by withdrawal of lava laterally or otherwise, a void is made in the mountain, and the walls of the terminal crater subside; the subsidence may be sudden or gradual, with floor and terraces or in a tumble of talus; examples, Mauna Loa and Kilauea.

(3) Craters of accumulation are the terminal cavities maintained open as vents for the building of detrital cones.

(4) Craters of mixed origin are made where engulfment, explosion, and detrital or lava accumulation succeed one another as phases of varied activity; Vesuvius is the type.

(5) Velain suggests an additional species, craters of lava accumulation of which the type is the Dolomieu crater in Réunion, formed with great regularity by lava overlap. Mercalli objects that this process would build a cone, not a crater, and that the crater there was made by engulfment in 1791 (p. 58). The writer urges a counter-objection that the vent, floor, wall, and rim were all present, brimming with liquid lava, during the constructional stages, and this is sometimes true of Vesuvius. Therefore the crater was there and was a true crater of accumulation (not detrital). The inner ring pools (Dana lake, Mercalli Tav. VI; Pls. 9, 10 here) of lava at Kilauea, almost perfectly circular, surrounded by ramparts of consolidation, and Wargentin on the moon, solidified with flat plateau on top (Pl. 29), are true lava craters of accumulation and should be recognized as probably the most primitive terrestrial type. Therefore, to make the above classification complete, the third group should be called craters of detrital accumulation, and there should be added Velain's group called craters of lava accumulation. It should be remembered that Kilauea and

Mauna Loa have had phases of activity when their larger craters (Kilauea and Mokuaweoweo) were overflowing and constructive, else their bedded walls could never have been piled up, and the same is true of the Icelandic pit craters. Halemaumau was constructively overflowing through 1919, and Kilauea the outer crater overflowed slightly in March 1921 (Pl. 45c).

Mercalli classifies the volcanoes of the world on the basis of (1) the acidity of the magma, and (2) a plexus of all the internal and external conditions that influence its emission. He does not clearly state that this is a genetic series but rather desires an arrangement whereby magmatic composition and dynamics of eruption harmonize. Taking trachytoid and basaltoid effusions as opposed types, he shows:

(1) Effusion predominates in basaltic eruption, explosion in trachyandesitic.

(2) Explosions are predominantly strombolian in basaltic eruption, exclusively vulcanian in trachytic.[14]

(3) The lava is more fluid in basaltic eruption, less fluid in trachyandesitic, and the slope of the cones varies accordingly.

(4) Lateral lava flows of normal Vesuvian type are wanting in active trachytoid volcanoes, common in basaltoid.

(5) Basaltic eruption shows more continuous activity; trachyandesitic eruption is intermittent.

Recognizing lava outflows as "the most pure (schietta) and most potent manifestation of volcanic activity", Mercalli classifies the principal earthly volcanoes "in the order of decreasing effusivity" (Table 4).

These are classed as (1) Kilauea type, (2) Vesuvius type, (3) Santorin type, (4) Pelée type, (5) Vulcano type, and (6) Stromboli type. In each case the last phase of the activity of the volcano in question is considered, without regard to its evolution in the past.

With regard to the distribution of these types of volcanoes over the globe Mercalli considers the "trachy-andesitic explosive" (Class 5) volcano predominant at the present day (continental shore lines). About half the existing volcanoes are of this kind, giving vulcanian explosions at long intervals. Second in abundance are the basaltoid volcanoes of mixed habit (Class 2), like Vesuvius and Etna. The places of great outflow of fluid basalt are limited to a few points, but the activity there is strong; Mercalli states that Mauna Loa was without question the most active volcano on the globe in the nineteenth century (p. 329). He concludes that all over the earth volcanic activity is incomparably less than it was in Tertiary and Quaternary time. He extends Geikie's notes on distribution as follows:

1. Volcanoes are very irregularly distributed; nine tenths of the earth *so far explored* is without active volcanoes. Japan and the Kurile Islands have 54 active vents, while the whole of Asia excluding Kamchatka has 11, and most of these mere solfataras in process of extinction (Mercalli neglects possibilities of ocean bottom).

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[14] Strombolian explosion ejects incandescent pyroclastic material directly from liquid lava; the vapors are reddish or white, and the heavy blobs show black only at the base of the jet; at night there is strong glow. Example: Halemaumau, March 1921.

Vulcanian explosion ejects much powdered old or new lava with the vapors making a dark-brown or black "cauliflower cloud", with angular blocks and bread-crust bombs, but without pasty or filiform or vitreous lava blobs; there are electrical flashes but no considerable glow (Mercalli, 1907, p. 119, 137). Example: Halemaumau, May 1924.

2. Without exception all the great modern lava floods are from islands in the sea. [Nyamlagira in Africa is an exception (Verhoogen, 1939).]

3. Volcanoes follow the bases of mountain chains, exceptionally the crests; in the ocean they follow submarine salients confined by deep troughs. They are probably aligned along the borders of areas of subsidence or along the lines of least resistance or fracture between subsidence and elevation (our ignisepta). The east African volcanoes are not exceptional, for they follow a zone of depression not occupied by the sea, but itself below the sea level.

TABLE 4.—*Mercalli's classification of volcanoes*

1. *Basaltic effusive type:* examples, Kilauea (Hawaii), Mauna Loa (Hawaii), the volcano of Réunion (Mascarene Is.), Masaya (Nicaragua), Varmardalr (Iceland).
2. *Basaltoid effusive and explosive type:* examples, Vesuvius (Italy), Etna (Italy), Lemongan (Java), Colima (Mexico), San Miguel (Salvador), Fuego (Guatemala), Kliutschewskaja (Kamchatka), Mayon (Philippines), Oshima (Japan).
3. *Trachy-andesitic type, prevailingly effusive (domes):* examples, Santorin (Kaimeni) (Greece), Bogoslof (Aleutians), Ischia (Cremate) (Italy).
4. *Trachy-andesitic explosive and effusive type (lava avalanches and mud lavas):* examples, Pelée (Martinique), St. Vincent (Caribbees), Semeru (Java), Papandajan (Java), Sangir (Moluccas).
5. *Trachy-andesitic explosive type:* examples, Vulcano (Italy), Krakatoa (Java), Tambora (Java), Coseguina (Nicaragua), Gountour (Java), Calbuco (Chile), Puracè (Colombia), Te Mari (Tongariro) (New Zealand), Pacaya (Guatemala), Tarawera (New Zealand), Azuma-san (Japan), and Bandai-san (Japan).
6. *Basaltic explosive (prevailingly) type:* examples, Stromboli (Italy), Izalco (Salvador), Bromo (Java), Sangai (Ecuador), Antuco (Chile), Aso-san (Japan), Gamalama or Ternate (Moluccas).

4. Volcanoes may be classed as
   1. Perimetric to the continents in the Pacific, Atlantic, and three great mediterranean seas (Latin, Caribbean, and Australian). (These are Lowthian Green's solstitial ecliptic belt.)
   2. Oceanic (Hawaii, Tonga, Samoa, New Hebrides, Réunion).

5. Submarine eruptions are generally in the vicinity of groups of insular volcanoes (Azores, Tonga, Pantelleria, Japan, Iceland).

6. The zones of major seismicity follow closely the alignment of active or recently extinct volcanoes. The greater number of earthquakes are intravolcanic, or peripheral to volcanic zones.

Mercalli's map of the world shows existing volcanicity, based on the number of active volcanoes and their "potency" (potenzialità) in historic time; it is a careful analytical study by a volcanologist of 415 volcanoes called active, 231 of which have erupted since 1800 A.D. There are hundreds of volcanic cones and craters in various relations of primacy and subordination, of freshness and degeneration, which have not been known to be active within man's recording.

Reviewing Mercalli's categories critically, and by comparison with those of Stübel, the writer would point out Mercalli's strong adherence to bare facts and sane disavowal of hypothetical bias. Mercalli does not concern himself with the moon nor with the genesis of volcanicity, though he clearly distinguishes pure (schietta) from mixed (mista) eruption, showing agreement with other modern writers (Stübel, Geikie, Suess, Daly, Rittmann) in believing basaltic-lava effusion the fundamental type of volcanic action.

In view of this the writer dissents from the position given the sixth class, "Stromboli type, basaltic explosive," in Mercalli's arrangement by "decreasing effusivity." Are not Stromboli, Izalco, and Aso-san more effusive than Tarawera or Bandai? The writer would place this group third in the list between the Vesuvius and Santorin types and make the two extremes of the series Mauna Loa and Bandaisan. So arranged, and with some doubt remaining as to the position of individual volcanoes, Mercalli's classification becomes an excellent working basis for a genetic series, representing the typical volcano from youth to old age, and the volcanoes of the world, from its primitive days to the present. On this basis and in this order, from pure to mixed, and from primitive to decadent, craters may be studied. A reservation must be made, however, to the effect that Bandaisan was phreatic when observed in 1888, and phreatic explosion is not magmatic volcanism.

T. A. JAGGAR 1910

The present author presented a genetic tabulation of active volcanoes at the meeting of the Geological Society of America (1910), suggesting kinship of origin of volcanoes and stages of growth related to a common ancestry. The classification was based on diversity of types measured by viscosity of lavas and temperatures of water vapor present at the stiff-lava volcanoes supposedly higher than at the liquid. As several authors have adopted viscosity as a rough measure of differences for purposes of classification, the table is presented here (1910, p. 6, Japanese Volcs.) only for its historical value. The writer sets no great store by the measured superheat of water vapor, and probably one of the high South American peaks should replace Fuji, as that volcano has some large basalt fields.

The measurement by Hovey (1908) at Pelée was made in a branch of the great fissure on top of the cumulo-dome of andesite where there were hundreds of steaming fumaroles. This was 6 years after the great eruption of 1902. Lower down beside the Rivière Blanche, 2 miles from the shore, Hovey read a temperature of 305°C. Lacroix (1904, p. 396), near here, read temperatures of 410°C. in July 1902, in what he considered vents of "deep origin." In view of the fact that the upper gorge of Rivière Blanche was described by Hovey as a "V-shaped cleft" in the southwest quarter of the crater and these very high temperatures were measured both during the eruptions and years afterward along a distance of 4 kilometers following the Rivière Blanche, the suspicion that that gorge may be a rift belt radial to the summit of Mt. Pelèe appears to be justified. This checks with numerous observations of cauliflower clouds (nuées ardentes) photographed jetting upward through the bottom deposits of that gorge during the time of the eruptions and justifies the suspicion that some of the violent steam blasts of such eruptions come from radial rifts in the bottom of gorges, largely concealed by the debris.

TABLE 5.—*Classification by viscosity, Jaggar, 1910*

Type	Lava	Petrography	Physiography	Activity	Probable intrusions causing elevation	Superheat of water vapor
1. Kilauea	Liquid	Basalt	Flat lens—pit crater	Continuous, and rare explosions, water scant	Intrusives nearly absent?	Measured at 300°C.
2. Vesuvius	Viscous flows	Leucite-tephrite	Lens and caldera under cone	Short intervals, lava and explosion	Few intrusions	Perret 323° to 438°C.
3. Asama (Omori)	Stiff low pile of block lava	Pyroxene-andesite	Cinder cone	Intervals, explosion, some lava	Elevated volcano probably over-intrusives	
4. Tarumai (Simotomai)	Rock dome	Hypersthene-andesite	Crateral dome on cone	Spasmodic, long intervals, explosion dominant	Elevated coastline movements diagnosed	Jaggar 458°C.
5. Pelée, Bogoslof	Rock dome and spine	Hornblende, pyroxene, quartz andesites	Spine and cumulo-dome, on ancient eroded cone	Very long intervals, intense explosion dominant	Positive elevation during eruption (Bogoslof)	Pelée, 1908 Hovey, 515°C. 6 years after explosions
6. Soufrière	None extruded	Dacite-andesite	Cone and crater lake	Very long intervals, water abundant, great explosion, no lava	Elevation, seismic area	
7. Fuji	Ancient only	Recent acid tuff	High cinder cone	Nearly extinct, rare slight explosion	Elevation and pronounced seismic disturbances	
8. Henry Mts. (Gilbert)	Laccolithic	Monzonite, trachyte, rhyolite	May have fed volcanoes (?) on sea bottom	Intrusion	Mostly intrusive, causing local elevation above	Probably much superheated water

F. VON WOLFF 1914

Von Wolff has reviews of classifications in volcanology, and his large book on volcanism is comprehensive and accents the petrographic side of geology. Like Sapper and other geologists, he uses the word "explosive" side by side with "effusive", quoting Dana as speaking of "semi-volcanic explosions", which Mercalli calls "ultra-vulcanian." Von Wolff was much impressed by Brun's skepticism concerning water vapor as dominating volcanism. He believed that, with the rise of temperature and heating of old glassy rocks to the explosion point, indirect eruption could be achieved without the direct access of surface water to make such explosions either semivolcanic or totally secondary. Science is loath to accept Daly's conviction that the secondary type of eruption, called phreatic, stands totally apart and is a surface happening just as much as the pouring of a lava flow into the sea, even though the exploding of ground water results from contacts with actual fluid magma.

The writer would cite Von Wolff as typifying the petrologic school in insisting on magmatic gas making explosion. To this school, a large lava fountain on Mauna Loa is identical with Krakatau in 1883. Both phenomena are different intensities of the release of magmatic gas. If this were true, the writer would have to believe that Kilauea, in May 1924, exhibited identical phenomena with Kilauea in March 1921. This is entirely unthinkable, and the writer believes that the world of geology has to face the fact that magmatic release of the carbon dioxide-hydrogen reaction to form water vapor is not explosion, does not make explosive eruptions, and does make intrusive irruptions generating much pneumatolysis along with other gases in migmatitic transfusion. Whatever the unknown condition of basaltic magma under pressure when eruptible, it cannot be other than the submantle magma and is not the product of melting.

So much is Von Wolff evidently puzzled by this dilemma that he divides his table of eruption types into "effusive" and "explosive", gives more characters to the explosive side, and then acknowledges that the two overlap. This is characteristic of almost all textbooks. It is occasioned by the fact that quantitative analysis largely excludes gases and deals with dead skeletons of magma, and by our ignorance of the variable part played by ground water.

Table 6 is Von Wolff's table.

K. SAPPER 1927

The formation of parasitic volcanoes is not always associated with the formation of cracks that give vent to lava outflow, according to Sapper. Parasitic cones may be the product of purely explosive processes in which case they may be arranged irregularly on the slope of the mother volcano.

Commonly, the number of parasites of a volcano is small, sometimes only one. In many volcanic areas, baby volcanoes may exist a short distance from the foot of the mother edifice, partly single, partly in groups (notably in Mexico), partly also in short rows that are almost concentric to the main center (Chingo in Salvador). Such volcanoes outside the main mass, when definitely parasitic, may be called attendant volcanoes.

TABLE 6.—*Von Wolff's classification of eruptions*

I. EFFUSIVE ERUPTIONS

Type	
Summit eruptions:	Lava flows from summit of volcano, and may be:
Intra-crateral lava flow	Lava flows inside the crater only
Kilauea type	Thinly fluid lava
Lava domes	Stiff lava
Summit overflow Cotopaxi type	Lava overflows rim of crater
Subterminal outflow Mauna Loa type	Lava flows from a rift not far from crater rim
Flank eruptions:	Lava rises in crater shaft and breaks through the flank of the mountain.
Vesuvius type, 1895	Quiet outflow of long continuance
Vesuvius type, 1872	Stormy outflow of short continuance
Excentric eruption:	Lava does not rise in central shaft, but breaks a new way to an outlet commonly at the foot of the mountain. Its activity is independent of summit crater
Etna type	

II. EXPLOSIVE ERUPTIONS

Phase	Type	Characteristics	Temperature
Phase of permanent eruption	Hawaiian activity	Very fluid new lava is flung high in molten condition from the surface of a lava lake in fountains	1200–1300°
	Strombolian activity	Rhythmic fling of a new material in fluid condition in the form of soft or half solid bombs and scoriae	1150–1200°
Phase of moderate activity	Mixed eruption	New glowing material either solid or liquid mixed with old material in fragments and producing much volcanic sand and ash	1150°
	Vulcanian eruption	New material mostly in solid condition, rich in ash, sand, lapilli, and bombs with either solid or pasty crust. Cauliflower clouds. Typical for andesite volcanoes	About 1100°
	Peléan eruption	New material in solid condition in large volume produced in eruption clouds that descend	About 1100°
Phase of paroxysmal explosion after a long interval of complete rest	Plinian eruption	At first old material solid and finely divided. Then new material solid in the form of ash. Explosions of great intensity. Pine-shaped eruption clouds, lowering of the mountain top and explosion opening of a caldera crater. No lava flow follows	About 1050°
	Semi-volcanic eruption (ul-	Only old fragmental material. Demolition of the volcano. No lava streams	About 1000°

Parasitic cones commonly show only moderate activity, but occasionally great explosive craters may exist on the slopes or at the foot of a stratovolcano indicating local development of great explosive power (Tahual in Guatemala); there are individual cases in which side explosions have happened in historic times, as at Santa Maria with its excentric eruption in Guatemala in 1902. There are other cases in Guatemala of attendant volcanoes some distance from the mother as at Retana Lake next to the volcano Suchiton, or Santa Catarina in Guatemala. More abundant as great excentric explosive outbreaks are those along the mountain axis, where caldron craters make fundamental changes in the topography of the country (Cosegüina, 1835; Ritterinsel, 1888; Krakatau, 1883; Vesuvius, 1906).

When activity reawakens as in Vesuvius after 1913, daughter cones may develop centrally or excentrically, at the bottom of the caldron. Also the explosion cavity may fill gradually with lava inflows, as in the decades following 1913 at Vesuvius.

Daughter craters may occur in other kinds of volcanic depressions than those due to explosion; such are those undermined and faulted down by outflow elsewhere, which cavities may break back to acquire a large diameter. In some cases daughter craters themselves may develop interior cones, as at Viejo in Nicaragua. A smaller daughter crater may develop inside a larger one that has gentle sloping walls. Within this a number of baby craters may be sculptured by explosion, as in the complicated summit region of Irazu in Costa Rica. Here in 1917 renewed activity partially destroyed former craterlets and developed a new grand-daughter.

Often within an explosion crater there develops a daughter cavity only slightly excentric to the original floor, which then has a ring plain around it as at Fuego in Guatemala. Or there may be a strong excentric quality to the new outbreak, leaving a sickle-shaped plain (San Miguel after the outbreak of 1890). Here, as a result of the renewed activity of 1919–1925, there were developed in the region of the old central crater shaft two larger explosion craters and four smaller ones about the ring plain, so as to change the topography. In other cases, like Nyamlagira in Africa, explosion craters are left with a flat bottom. Sometimes remains of ring terraces surround the central shaft; there are three of them in Poas, Costa Rica. It is impossible to list all the manifold combinations. The commonest arrangement is a simple crater without daughter cavities or complications.

The word crater ordinarily means a relatively large funnel or shaft, sometimes of irregular form on a volcanic edifice, out of which magmatic material, either fragmental or lava, has been thrown in large masses.

Original craters may be divided into three groups:

(1) Concentric construction crater, funnel-shaped, built so that the material thrown out makes a surrounding ridge, with concentric inward and outward slopes.

(2) Explosion crater, a pit or shaft hollowed out by gas through volcanic or non-volcanic formations, eroding away a cavity.

(3) Inbreak or engulfment crater, shaped as a sinkhole or inbroken fissure, producing a caldera by collapse or the sinking of magma.

As most craters have a prolonged and changeable history, with the removal process often changing, the forms of craters are manifold. In the case of explosion craters there may be only a smooth wall, but in some cases radial cracks extend outward for a short distance, as in the eruption of Krakatindur in Iceland in 1878. While the distinction between the three types of craters offers commonly no difficulty, it is hard to distinguish explosion craters from engulfment craters.

It was formerly thought that a necessary sequence of explosion was that the marginal wall should be built up of the outthrown materials. Observation has shown, however, that explosion craters often leave no such deposits on the edges. Many disbelieve in the possibility of this. Jaggar determined at the last explosive eruption of Kilauea (Jaggar, Haw'n. Volc. Obsy., Bull., Dec. 1924) that there was thrown out only 0.0008 cubic kilometer of material, whereas 0.21 cubic kilometer of rock disappeared into the depths—253 times as much—sufficient to correspond to an upright cylinder of fragments almost 1 kilometer deep and half a kilometer wide! Since this determination there is increased belief in the formation of large craters by engulfment.

Above all, it should be remembered that widening and deepening of craters may depend upon marginal breakage of rock which falls into the rift, far below what is visibly lost from the crater rim.

If we disregard genetic classification, the simplest way to distinguish crater types is by material of which crater walls are built, apart from petrographic distinction. We may interpret and evaluate the nature of activity by whether the crater wall is made of lava or loose material.

Sapper discusses the usual distinction between craters of fragmental material (cinder cones), craters with lava walls, and mixed craters, citing many examples. This leads to the question of localized reservoirs of magma and all the complications of its fluid outflow, compared with the stiff-lava type of volcanoes as developed by Stübel in South America. Referring to shield volcanoes, Sapper makes the following comments on relationships between lava and sea water; lava flows appear to develop forms under water similar to those formed subaerially. Some gases may be abstracted from the water; others go through it into the atmosphere. Obviously, soluble sublimates cannot be preserved on submarine lava flows. The lava in a place of sudden cooling forms platy or columnar joints. Probably in a submarine lava flow the magma may break up in small fragments, but the same thing happens in subaerial lava flows. This raises the question of whether aa surfaces exist under water and the much-discussed question of "pillow lavas." As lava pours from a height into the ocean it explodes into sand and cinder which fall along the shore and may form hills of fragments flung hundreds of meters, as in Savaii and Hawaii.

It is possible, however, for lava in water to show no explosive phenomena. Neumann and Gevers (1925) report the building up of a lava dome in the crater lake of Gunung Galung-gung in Java without explosive phenomena and explain as follows:

> "It is noteworthy how the red hot lava mass some meters under the lake surface can remain in such placid contact with cold lake water. It must be assumed that an equilibrium exists between steam pressure and pressure of the surrounding water. Since this can be no accident, we have here a proof against the assumption that eruptions must follow from the pouring in of ocean or lake water to an unobstructed crater fissure, and its contact with magma. Moreover, the fact should be noted that the lava entered the crater lake without ejecting the water. It was not until the plug first emerged from the water that sulphurous gases, ash, and bombs were thrown up, not from a depression in the top but out of cracks and fissures."

Although shield volcanoes generally develop no strong explosive activity, yet occasionally they do so as in 1790 and 1924 at Kilauea, when cauliflower clouds were thrown up. In other cases short-lived explosive activity leads to an effusion of long duration, as at Matavanu in August 1905. Here a slag cone was built up in the same crater where a lava lake endured. The broken material of explosive activity is often covered by lava so as to form layers between lava flows, as seen in sections at Kilauea.

Lava flows play the leading role in building up shield volcanoes, and there are cases quite apart from the ejection of fragmental material, whereby steeper lava domes, made of stiff lavas with outer slopes around 15°, are piled up (las Flores and las Viboras in Guatemala).

High gas content is very important in the morphology of crater types by reason of its effect on the small units of lava structure.

The upper surface of lava is either roughly ruptured and broken within a crust of slabs and blocks, with sharp angles and scoria, or it is smooth and coated with slaggy and ropy crusts. The first type is called block lava—the aa of Hawaii, apalhraun of Iceland, graton of Réunion. This is clastic and very difficult to travel over as a result of strong gas emission from viscous magma. The second type has smooth or slaggy lava—the pahoehoe of Hawaii or helluhraun of Iceland; it flows without any strong effervescence of gas and has a tough glassy skin. Jaggar (1917) has given the name "aphrolith" to the first type of lava crusting and "dermolith" to the second type, in order that the two processes might have suitable adjectives—aphrolithic or foaming, dermolithic or membranous.

The differences of size of volcanoes are various. Parasitic volcanoes may be only a few meters high, made of lava or fragments, with craters 1 to 2 meters in diameter. A perfect model volcano may be only 30 to 40 meters high like its gigantic counterparts from 2000 to 3000 meters high. Some volcanoes reach heights higher than 6000 meters above sea level, but these are built upon a high mountain ridge as in the case of many of the volcanoes of the Andes, like Chimborazo, 6310 meters elevation, on a mountain structure that is already 4000 meters above sea level. The peak of Teneriffe rises above deep water to 3700 meters of height, and the lava volcanoes of Hawaii, standing over 4000 meters above sea level, rest on an island 5000 meters above the deep ocean bottom. Here we have volcanoes 8 to 10 kilometers high if we assume that Hawaii is built entirely of volcanic material. In this case the diameter of the base would be more than 100 kilometers.

Penck has presented a diagram where existing well-known mixed cones and lava-shield volcanoes are compared in profile. As a structure on the surface of the earth, Mauna Loa appears 10 times as great as such volcanoes as Vesuvius and 3 times as high as such volcanoes as Teneriffe, Réunion, and Etna. (See volcano profiles reproduced by Sapper, p. 215, erroneous scale.)

As with mountains, craters and calderas show great differences of size. There are innumerable little craters on earth less than 100 meters in diameter, whereas others reach a kilometer or more. These range from 1 to 23 kilometers, and the craters of East Africa are in some cases much larger. (The crater of Elgon is said to be 25 miles in diameter.)

Sapper has classified the greater volcanic districts in the order of the bulk output respectively of fragmental material and of lava, for the historic period within which rough data exist for such computation. Different methods have been suggested as to what constitutes comparative volcanic activity. There is Von Wolff's *Index of decadence*, where an index number is applied to the percentage of extinct volcanoes for the total number of a district; or for the total number of historic outbreaks; or the number of volcanoes active for the aggregate length of the volcanic zone; or the volume of output, which shows the maximum quantity of lava at the opposite end of the list from maxima of explosive material.

TABLE 7.—*Sapper's bulk output, fragmental materials, and lava*

Period 1500 A.D. to 1914 A.D.

	Cu. Km. fragmental		Cu. Km. lava
1. Java belt	185.0	1. Iceland	15.5
2. Central America	58.0	2. Central Pacific	11.0
3. Alaska-Aleutian	30.0	3. Indian Ocean-Africa	8.0
4. Iceland	10.0	4. Atlantic Ocean	5.5
5. South America	9.5	5. Mediterranean	5.1
6. Japan	8.2	6. Kamchatka-Kurile	5.0
7. Philippines-Molucca	6.5	7. Japan	3.5
8. Kamchatka-Kurile	6.0	8. Alaska-Aleutian	2.0
9. New Zealand-Tonga	4.1	9. New Zealand-Tonga	2.0
10. North America-Antilles	3.5	10. North America-Antilles	1.5
11. Mediterranean	3.5	11. South America	1.2
12. Melanesia	3.1	12. Philippines-Molucca	1.2
13. Atlantic Ocean	2.2	13. Central America	0.6
14. Indian Ocean-Africa	2.0	14. Java belt	0.5
15. Central Pacific	1.5	15. Melanesia	0.1

Iceland leads the world in output of lava, and the Dutch East Indies in output of fragmental deposits. The oceanic islands and subarctic regions are great lava producers, while the continental borders and the equatorial belt produce much explosion.

Table 7 is from Sapper's revised tables (1928, also Volcano Letter, No. 355). Clearly, explosive violence and lava outflow are geographically opposed, and if either of these qualities is to be used as a measure of volcanic activity the other should be a measure of decadence. If the rise of primitive magma and exclusion of ground water is what leads to lava flow, and if engulfment and admission of ground water lead to explosion, then only the former truly magmatic action is a measure of pure volcanicity.

Decadence of volcanism may mean a transition from basaltic flow lava to andesitic intrusive lava. Some volcanic regions may be characterized by intrusive magma in just as great volume as anything poured out in Iceland or Hawaii. The underground contact with surface water would make steaming solfataras and boiling springs, would deposit sulphur and sublimates along cracks, and, if the intrusive magma lowered to let in ground water, explosive eruptions would result, and the little lava exhibited would be a stiff plug or dome of siliceous andesite, a structure well known at many explosive volcanoes. No intrusive region of olivine basalt apart from volcanoes has been discovered, except for some gabbro sills, so that assimilation of silica would seem to be a common function of the gaseous irruption of the act of intrusion of deep basic magma.

TABLE 8.—*Comparison of eruptions and large earthquakes by latitude*

Latitude northward or southward	Numbers of eruptions	Numbers of eruptions per 10 million sq. km.	Numbers of earthquakes	Numbers of earthquakes per 10 million sq. km.
0°–10°	944	107.0	450	50.8
10°–20°	826	96.5	329	38.3
20°–30°	238	29.6	244	30.4
30°–40°	437	60.0	258	35.4
40°–50°	157	24.9	152	24.1
50°–60°	101	19.7	87	17.1
60°–70°	47	12.4	21	5.6
70°–80°	115	49.5	9	3.9
80°–90°	0	—	1	1.3

Sapper makes the following comments:

> "Iceland in a period since 1500 A.D. has exceeded all other places in output of lava, in that it has poured out a third of the world's lava production, or about 16 cubic kilometers out of a total of 50 cubic kilometers. Hawaii comes next to Iceland in lava output.
>
> "In the production of broken material, the Dutch East Indies have produced more than half of the 325 cubic kilometers ejected on earth since 1500 A.D., with Central America coming next, and the Aleutian Islands in Alaska third."

Central America, being the shortest belt, is the most productive of explosive material per unit of area. When these three belts are examined in detail, each shows the two ends of the belt less productive than the middle, as though the fracture system (igniseptum) were most open in the middle region. It is remarkable that the three most productive regions on earth have intrusive volcanism manifested by explosive material give evidence of cycles of intrusion at the present time, and all lie in inter-continental areas—Java between Asia and Australia, the Aleutian Islands between North America and Asia, and Central America between North and South America.

In discussing Sapper's geographical statistics, Table 8 by latitude north and south of the equator for numbers of eruptions per unit of area is of interest in comparison with a similar table of numbers of large earthquakes (Volcano Letter, No. 198, 1928; Bellamy, 1936).

For both eruptions and earthquakes the tabulations concern the two first decades of the twentieth century when records were numerous. Both eruptions and earthquakes are more numerous in the equatorial belt, are few near the poles, are distributed between the northern and southern hemispheres fairly equally, and both tables shown a break at about latitude 40 in the direction of increased numbers, as though there were some differential stress in the region intermediate between equator and pole. (*See* Summary and Conclusions, equatorial protuberance.) Maurain theorizes (1927, p. 612) that distribution of mass may be sufficiently uneven with reference to equilibrium between centrifugal force and terrestrial gravity to produce greatest tensions at the equator. The belts of 40° latitude will bear comparison with sunspot solar latitudes.

R. A. DALY 1933

Daly occupies foremost rank for his studies of batholithic intrusion and its correlation with volcanism. Modern volcanology may be said to date from his paper of 1911. He assumes abyssal injection from under the earth's mantle as an essential premise and makes the causes for lava outflow (1) deformation of magma chamber, (2) effervescence by periodic accumulation of juvenile or resurgent gases, (3) assimilation of country rock, and (4) increase of volume in the conduit furnace through heating during the dormant period.

Daly sharply distinguishes phreatic eruption as nonvolcanic. He defined volcanic action as "the working of the extrusive mechanism which brings to the earth's surface rock-matter or free gas, initially at the temperature of incandescence." The processes of eruption are divided into fissure eruption, foundering eruption, and central eruption; the mechanism of the last may be by enlarged fissures, by blowpiping, or by magmatic drilling from plutonic cupolas. Eruption at a central vent is a heat problem, the vent is a true furnace, the rate of loss of heat is quantitatively very great, heat is transferred from the depths by two-phase convection, and the origin of the magma itself is what Daly has studied as his life work. Just as the heat loss at a vent is enormous, so the heat conductivity of solid rock is astonishingly small. (*Compare* Dutton above.)

Daly's most fundamental work has dealt with genetic classification of magmas. He believes in large development of secondary magmas within the earth's crust. The primary magma under the mantle is basalt. Batholiths arrive at continental differentiation by assimilation of the crust and not by pure injection and direct crystal fractionation. This agrees with the increasing acceptance of granitization by transfusion of older rocks with liquids and gases from fundamental magma. Unmixing of liquid phases of silicate melts is doubtful, gravitative separation is a leading process, and crystal fractionation under gravity and by filter-pressing is a demonstrated process, "to be ranked not higher in efficiency than the self-cleansing of basalt, either contaminated or temporarily enclosing the products of pure melting."

Daly's genetic classification is given in Table 9.

Most such petrologic discussion of magmatic differentiation by some form of assimilation is confined largely to continents, now conjectured to be over the place of some original separation of a siliceous earth crust into blocks or island masses distinct from the heavier magma of the great ocean bottoms. Daly's gas fluxing as represented by pneumatolysis, transfusion, and granitization may continentally go far beyond the "production of some lavas" into the realm of intrusive assimilation and metamorphism.

Daly, in a recent contribution (1938b), points out that the source of quiet emanation of gas is the chief problem of volcanology. At each center there is a chamber of vesiculated molten rock. Localized injection is essential. The roots of volcanoes are injections into the crust from a layer of vitreous basalt below. He suggests an earth model of crust and substratum to satisfy the notion of an abyssolith or fundamental substratum protuberance under every volcanic field; this is harmonized with intrusion and petrography, mountain building and continents, gravitative adjustment, and earthquake science.

TABLE 9.—*Daly's genetic classification of magmas*

Magma	
Primary basaltic	Plateau basalt, diabases and gabbros
Primary sialic	Primitive siliceous crust
Anatectic Granitic	Pre-Cambrian granites
Differentiates of primary basalt	Peridotites, iron ores, sulphide ores, and anorthosites
Pure melts of crust rocks at depth	Some granites, granodiorites, etc.
Products of gas fluxing	Some lavas at volcanoes of central eruption
Differentiates of pure melts	Some granites, granodiorites, etc.
Hybrid of basaltic liquid with:	
A. Sialic crystalline rocks	Some bodies of intermediate composition
B. Sediments	Hybrid types
C. Sediments and sialic crystallines	Hybrid types
Differentiates of these three classes	Some granites, syenites, etc.
Hybrids with magmas more acid than basalt	Miscellaneous types
Differentiates of these hybrids	Miscellaneous types
Transition magma marking incomplete differentiation	Intermediate types
Mixtures of two or more liquids	

The crust in thermal equilibrium is thinner under siliceous continent than under basic ocean bottom. Eruptive pressure is a special by-product of isostatic adjustment, at fracture of the crust which goes through. The glassy substratum is extremely weak and matches the qualities of hot glass. Short-lived elements inherited by the earth from the parent sun and trapped at great depth in the planet probably yield the heat of radioactivity or nuclear reactions needed to meet the criticism of mathematical physicists. Earthquake wave motion and deep earthquakes in different viscosities of material under pressure are too unknown to justify any precise assertions about effects on transverse waves of a layer of vitreous basalt 60–80 kilometers under, respectively, continent and ocean. The objection by Jeffreys to a crust substratum earth model based on triaxiality of the figure of the earth is met by the belief that the inequality of the resulting distribution of mass and the corresponding stress differences are restricted to a pressure-solid, centrospheric shell, leaving the relatively thin substratum unaffected. The writer objects to the word "solid".

Daly's summary of the picture as concerns volcanoes is that the feeders are molten masses injected upward from a vitreous, gas-charged substratum of basalt. The injected magma may be contaminated with the material of the invaded crust according to contacts and duration. The mechanism explains volcanic vents, duration and periodicity, extinction, varied composition of lavas, and geographical relations, whether the vents be aligned along through-going fissures or irregularly scattered by gas fluxing above intrusive sheets.

Daly is one of the few geologists who recognizes fully, and discusses, the limitations of our knowledge of rock under the great oceans. He (1938a) analyzes what little we know from soundings and islands and separates clearly those island ridges like the Azores and the middle Atlantic, and the New Zealand-Fiji Plateau bounding the western Pacific, which are continental in containing granite. This is in marked contrast to those places like the deep-sea islands of the Indian Ocean and the islands in lines of the Pacific Ocean where the fundamental rock is basalt, and "not one island of the central Pacific has yielded a single piece of rock rich in quartz or indeed any of the rock types that are found in the continents." The logical inference is that the continents are siliceous and fundamentally different and that transfusion of siliceous and argillaceous sediments by volcanic emanations accounts for the acid and alkaline volcanic rocks that differ from basalt. The widespread and growing acceptance of Daly's general thesis stimulates growth of this doctrine.

If there is any one point of Daly's conception of the inside of the earth wherein the writer thinks differently, it is in his notion of quiet emanation of gas, gas fluxing by matter in a vaporous condition, rather than by magma containing it, and a substratum related to concentric shells. The acceptance of the seismology divisions of rock shells of different densities as uniform and worldwide is not yet to be taken as natural law. The notion of thermal equilibrium and quiet emanation within an earth, thought of as at comparatively low temperatures 100 kilometers under the surface, and behaving as rigid, may have done much to prevent clear thinking about the great volcanic belts and their profundity. If these belts of irregular shape but quite long, which may be called ignisepts, are permanent in relation to the primitive globe, like the continents and deeper oceans, as septa separating continents from sea floors, and like some elongate features photographed on the sun and on the moon, there is every reason to think of their thermal gradients as maintained distinctly high by intrusive action throughout the ages. The maintenance of ignisepta, distinctive volcanic deep fissures in the earth body, widening downward in an earth box far from uniform, may mean internal temperatures there much higher than in nonvolcanic places, just as the surface gradient today is notably different in Central Canada, the Sierra Nevada, and in Hawaii. Add to this our complete ignorance of the sea floor. (*See* Suess above.)

When it comes to thermal equilibrium and quiet emanation, in the mostly continental studies of differentiation, which have so influenced the thinking of petrology and physical chemistry of the silicates, we have to remember, from experimental volcanology, that lowering of magma has never been given its due. In the magmatic volcanoes repeated lowering is an enormous process, and in the explosive ones it is the fundamental cause of their explosions by letting in ground water. As they are all located above ignisepta, marks of an internal geometry of intrusion, and are all graded downward to internal phenomena of sudden gaseous transfusion as the equivalent of what on the surface is called volcanic activity, there is no escape from both lowering and rising as processes of magma in the inner earth. So-called reservoirs are not only filled but emptied in an earth kinetically breathing by intrusion. Critical studies of Yellowstone hot water showed approximately 12 per cent to be magmatic (Allen and Day, 1935). The same authors discovered magmatic water at Geyserville, close to the center of the San Francisco earthquake, in Lassen hot-spring district, and Grange (1937) found it in New Zealand. Here are cases of transfusion by oxidized magmatic hydrogen, and the profound water-gas reaction (Jaggar, 1940), in shrinking the magma of intrusion, creates lowerings as well as risings.

If pulsation of both lowering outgassed and rising ingassed magma is going on in the fractured earth mantle, the magma being laterally distributed from the fundamental deep volcanic ruptures or ignisepta, then we have to grant a kinetic world of intrusion within a box of nonuniform profound earth shell, influenced in its heterogeneity by earth history of continents, oceans, and great volcanic rupture partitions. The type volcanoes worthy of magmatic study, or index vents to profound terrestrial heart blood, are not over "reservoirs." In all of this Daly's conception should be extended to (1) possible nonuniform earth shells, (2) possible very deep volcanic belts, and (3) possible subterranean magmatic pulsation and magmatic pressure. This is related to abyssal movement, and its geophysics is all unknown as concerns more than half the earth's outer shell, the sea-floor rock foundations. We are ignorant of this area with reference to local topography, volcanoes, thermal gradient, gravity, seismometry, petrology, diastrophism, gas emission, ground water, and chemical reaction changes affecting sea water. As long as geophysics remains a science mostly of continents and closets, without ingenuity, expense, or inventive exploration applied to the deeper bedrock of the oceans, geology will remain an impure science of mere detective assistance to commerce. Geology has never made any effort to vie with astronomy and astrophysics in precision, universality, expensive invention, and as a pure science. And yet every square kilometer of earth surface is in some sense physically accessible, at least with a wire, a motor, and automatic physical apparatus, and is subject to penetration with a core drill.

A. RITTMANN 1936

Rittmann has studied Vesuvius (1933), Etna, and Stromboli in the Friedlaender institute at Naples, and his textbook (1936) is a modern petrologic product. The volcanic process hinges on Niggli's (1919) thesis that reduced pressure or raised temperature set the limits for solution of gas in magma. Internal vapor pressure increases with lowered temperature to a specific maximum. With cooling of superheated magma, vapor pressure increases; between 1200° and 750°C.—the orthomagmatic zone—ordinary eruptive rocks crystallize, with residual fluid showing rising pressure as temperature lowers; next comes the pegmatite-making condition, 750° to 550°, with vapor pressure at maximum; with loss of heat comes next the pneumatolytic field to below 400°, with both pressure and temperature lowering. Nearer the surface with continued cooling comes the hydrothermal zone with small vapor pressure further declining, with temperature below the critical point of water.

When magma is at the superheated or orthomagmatic stages it can force its way to the surface. Energy is conditioned by heat and gas content. When the energy is that of early stages of magma, the condition of rupture fits production of shield volcanoes; if the energy is that of somewhat later magma residuum, a strato-volcano is produced; if the rupture is that of a very late stage, a single explosive eruption occurs, followed by caldera collapse. This does not exclude the possibility of indirect phreatic explosion due to ground water, when such is absorbed or confined. A condensation by Rittmann of Sapper's tables shows oceanic volcanism to be effusive, continental mixed, and orogenic volcanism excessively explosive and productive of clastic material. This is worthy of comparison with Bellamy (1936) where in her Figure 1 and Table II world earthquakes are four times as numerous in the continental quadrant of the globe northeast of Greenwich as in any other, including much of the orogenic volcanism. Here is an additional geographic link between volcanicity and seismicity, with seismicity possibly the remnant of orogenic volcanism of the past.

Geophysics teaches according to Rittmann that sima (salsima) is worldwide under sial of continents, and sima 70 km. down cannot be crystalline. It is amorphous and viscous, rigid to short stress, and yielding to prolonged deformation, by the dicta of seismology and isostasy.

Basaltic magma in geologic history makes up more than 95 per cent of all lavas including the lava floods of the continents. The Pacific type is an olivine-bearing titaniferous augite basalt, the equivalent of the primitive ocean volcanism and sea-bottom crust. The most difficult question is the origin of the continental sial. Either the primitive earth differentiated clusters of siliceous shell blocks or the sial blocks now found are migmatitic products of the first erosion refuse, pneumatolytic exudates, and more or less differentiated residues of the still-present weak Atlantic olivine basalt magma. Rittmann favors the last alternative of assimilation as prime cause of the granite uplands and granitized mountains, as not in opposition to magma laws and as not disturbing the principle of lowering temperature accordant with rising vapor pressure, along with crystallization and impoverished mother liquor.

A. HOLMES AND H. F. HARWOOD 1937

These authors working on the Bufumbira lava fields in the rift depression of Uganda discovered four main groups of alkali rocks: olivine leucitite, melilite-feldspar basalt, leucite-basanite, and potash trachybasalt. These contain inclusions of plutonic rocks. Extensive rock analyses converge to biotite-augite peridotite. Practically all lavas from the district contain more potash than soda. Genetic processes, as a result of discussion of data, cannot involve the co-operation of original basalt or granite, and carbonate syntexis does not apply.

Recent field studies demonstrate the feldspathization of quartz and quartzite and the granitization of sediments and schists by alkali-carrying emanations immigrant from magma.

The authors explain what they find by transfusion and evolution of seemingly magmatic products from pre-existent solids. There are in-coming emanations from deep active magma; there is energy secular, radioactive, or ionic; there was crystal rock material transformed into magma; and there were outgoing emanations producing metasomatic and migmatitic effects, including hydrothermal ore deposits.

This investigation, considered as ranking with the great synthetic studies of assimilation in modern petrology of W. C. Brögger, R. A. Daly, and E. B. Bailey and his associates, marks the triumphant emergence of acceptance of the general principles of Daly's gas-fluxing hypothesis, as applicable to all granitization and metamorphism in some measure wherever found. Here it emerges at the very hearth and center of "Kilauean" eruptivity of the present day, the Lake Kivu or Virunga (Verhoogen, 1939) volcanoes.

The Scottish geologists find all stages of an ancient Kilauea, even to its structural crater, amid the Tertiary intrusives of Scotland and Ireland. In Norway, Brögger (1931) finally discovers in that land of granite and gneiss what he called the great Hurum Volcano, just as Daly (1903) had learned his first lesson on the roots of volcanoes from the syenites, granites, and diorites of Ascutney Mountain in Vermont. The school of modern volcanologists, Friedlaender, Rittmann, Sapper, Van Padang, Escher, and Van Bemmelen, are imbued with the spirit of freedom in thinking of magma and its viscosity as changing from basalt to andesite, as capable of gas fluxing and assimilation, in recognizing the superlative power of gas, and in considering downward movement in craters as important evidence of much deeper engulfment and downfaulting, and characteristic of volcanism.

Bowen (1938), leading expositor of fractional crystallization, has recently discussed the magmas of the African rift system with reference to Holmes and Harwood. There is a structural north-south trough in East Africa with tension faulting extending through Abyssinia, associated with soda-rich rocks. A similar trough north-south along the western lakes through the Virunga (or Birunga) volcanic belt had potash rocks and compression faulting. Harker and his successors had defined petrologically a Pacific group of subalkalic or lime-magnesia rocks which came to be associated with folded mountains and an Atlantic group of soda-potash rocks associated with crustal foundering. Later a Mediterranean group of distinctively potash rocks was associated with early folding stages, and the western compressional rift of Africa was thought to support this by both tectonic and chemical (potash) evidence, in contrast to the foundering and soda associated with the alkalic lavas of the eastern tension faults.

Bowen concludes that soda-rich rocks frequently occur in regions of foundering, but we are uncertain of any connection between tectonics and magma chemistry. "Foundering" is ambigous in a region of mass uplift like Africa. The African continent does not encourage belief in the control of tectonic forces over the composition of igneous magmas. With Holmes he agrees that the contamination of a soda-rich magma by selective reaction with biotite pyroxenite is one possible explanation of the origin of potash-rich types. Verhoogen (1939) finds powerful sodium D line in spectrogram of active lava flames of the prolonged Nyamlagira eruption, states that analysis of the contemporary lava has not been made, but comparing Hawaii and Kivu, deep sea and continent at the two antipodes, he considers Hawaii more mature, the types of activity in Kivu more variable, and Kivu lavas more complex and more alkalic, with absence of basalt in technical sense (kivite has 43 per cent SiO_2). The optical measures of temperature, in 1938 Nyamlagira lava stream, reached maxima of 1095°C. In comparison with Verhoogen's spectrogram (1939) showing the D line and nitrogen band, Romberg and Jaggar (Bulletin, August 1918, 3 figs.) photographed at night a flame at close quarters through a spectroscope, north side of Halemaumau, and obtained the D line and a neighboring band. Using only prisms, they photographed repetitive flame ghosts some distance from the images of the principal flames, along the continuous spectrum of the melt, toward the red.

HOWEL WILLIAMS 1944

In his 20 years of field work on the volcanoes of California, Oregon and Washington, Williams has brought volcanology more up to date than the content of this book, and volcano geology has made important strides in the last decade. This is reviewed in his chapter "Volcanology" (1941a). Important features of progress are his classification of pyroclastics (1926), of volcanic domes (1929; 1932b), of engulfment calderas (1941b; 1942); and by critical study of Lassen volcano and other peaks of the Cascade Range in comparison with world-wide studies of the Netherlands, Hawaiian, German, French, Italian, and British geologists, he has summarized the contact of volcano geophysics and geology.

H. T. STEARNS AND G. M. MACDONALD 1946

In concluding notes on classifications in volcanism where we are dealing largely with Hawaii, mention of these geologists and their associates is essential. They have produced a succession of monographs on the volcanic geology of the eastern islands, and Stearns has classified a succession of stages of growth in basaltic volcanic islands ably illustrated (1946).

Macdonald's petrography of Maui (Stearns and Macdonald, 1942) finds the oldest lavas of the Haleakala end of the island, which is also the "active" end, to be olivine basalts like the primitive lavas of the other Hawaiian volcanoes. The later lavas include basalts, basaltic andesites, andesites, and picritic basalts, without normative nepheline. The greater the frequency of eruptions indicated, the less the amount of differentiation. The age of this modern end of the island Maui ranges from recent to Pleistocene.

The western, older volcano of Maui was built above the sea in Miocene time by an older series of olivine basalts and less abundant ones that are poor in olivine, also hypersthene- and picritic lavas. Completed in Pleistocene time were eruptions of oligoclase andesites and soda trachytes. In late Pleistocene came the Lahaina eruptions, which have their counterparts on other islands of Hawaii, exhibiting nepheline basanite and picritic basalts. Intruded into the early lavas of West Maui are coarse-grained gabbros.

Macdonald concludes that crystal settling influenced differentiation, and that the alkali curves of the variation diagram indicate that soda and potash formed volatile compounds of low boiling point, moved upward through the liquid phase, and enriched the uppermost part of the magma chamber with alkali minerals. The basis for this is that at about 47 per cent silica, on the variation curves for soda and potash, a rapid reversal in trend from down to up occurs, characteristic also of the Koolau volcano on Oahu island where its nepheline basalts are included among the analyses.

CRATERAL PHYSICS AND CHEMISTRY

MAGMA

It is well known that lava pours out from volcanoes, representative of magma underground, defined in the laboratory as a rock slice in the microscope of the petrological mineralogist. It is not so well known that eruption is an act of differentiation from glass compressed to vesiculate glass sponging out gas (the "expansive vapors" of Dana), thereby mixing gases, heating itself by exothermic reactions, involving oxygen, stirring up crystallinity in a melt that was vitreous, changing to higher viscosity instantly when gases escape, making flames when they are inflammable, and thereby creating oxidized gases of great potency as acids. The residual viscous magma, gas-free or engaged in gas emission, is the greater part of the lava column after vesicular foaming starts. Since all this surging turbulence begins anywhere in magma when a cork is withdrawn, or a crust block yields, or a weight of superincumbent liquid lava is transferred, and this turbulence changing viscosity may be propagated far down among intrusives, no hard and fast line exists between volcanism and deep irruption. Oxidation catalyzed in the lower magmas may liberate ionized gaseous atoms. Furthermore, any open chamber over lowered magma fills with oxidizing and reacting gases capable of remelting the ceiling to glazes that rearrange crystallization. The principles involved in gas heating and gas-tight solidification at selvages are so totally unknown that almost anything is possible for the deeper thermal gradient. This gas melting of walls and ceilings is described repeatedly and photographed (Pl. 7).

GAS IN SOLUTION

The minor volume of volatiles in magma is current report in geology, with importance given to juvenile water vapor. This doctrine is probably simply error. The experience of volcanologists at really primal magma effervescing and flaming is that hydrogen, carbon monoxide, and sulphur are burning and that this combustion goes deep. They have no experience whatever of the real volume of volatiles in the depths. Water vapor is the most abundant combustion product because hydrogen is the main terrestrial gas, just as it is the principal solar gas and the universal nuclear element. The volcano is an experimental vessel that can burn hydrogen quietly with the aid of carbon dioxide and magma at 1200°C. (Jaggar, 1940). The earth crust beneath it and around it, the perilith, is a laboratory utensil that can do a good job in holding hydrogen at high temperature with the aid of magmatic glass under pressure. It holds it better in the batholithic zone. It holds it in some remnant solar condition deeper down. None of these operations yet has admitted of laboratory test; nothing in the chemical laboratory will hold hydrogen at high temperature.

The ocean is proof that primal volcanism burned hydrogen. Life, air, and limestone are proofs that it burned carbon, and atmosphere and rock prove that volcanism used oxygen and supplied nitrogen, argon, helium, silicon, and the metals. All this is solar, and the geologist's uniformity intuition should lead him to search for solar matter and solar-nuclear reactions under the rock shell. This instinct cannot logically induce him to compute centrosphere composition by lithosphere composition. What the core discards should quantitatively be the inverse of what it retains. There is no logic in an order of abundance of elements for the 3500 kilometers of radius of fluid interior of earth, based on 20 kilometers thickness of surface sections in continents and islands, these limited to existing geological collections, and the area less than 30 per cent of the earth's surface actually accessible to man. The only logic in current speculation on "iron core" is a group of three feeble analogies: iron meteorites, angular momentum, and planetary mass. The origin of meteorites is not terrestrial. The data of density distribution would be completely satisfied with some of the 62 elements that are denser than iron. Of these there are 38 in the atomic state more than twice as dense as iron, not counting what pressure and temperature might do when all are ionized and mixed with the so-called "gaseous" elements in a mutually dissociating solvent. Effective insulation against escape of internal elements is demonstrated by the paucity of external vents today. Geologic history demonstrates overpowering restraint of volcanism by hydrogen monoxide and its trivial sedimentation, so that even geologists take no interest in trying to measure present-day intrusion and earth radiation. An exploded earth would not yield broken iron from its fluid center. The "iron core" doctrine is another unproved assumption.

That gases are in solution in basaltic glass is experimentally proved, and natural wells have captured excess of helium. Everything in this book about observed Hawaiian glass fountains shows the melt surcharged with partly combustible gas to the last splashes and slops of vitreous matter that blister and bubble as they cool. Fresh lava gas invariably shows hydrogen and water vapor. No temperature in external volcanism remotely near dissociation can be imagined to derive the former from the latter, whereas the pale flames are always present when the gases are confined. This is true not only of Hawaii, but of Nyamlagira, Stromboli, Vesuvius, Etna, Santorin, Tonga, Samoa, and Oshima. At the live lava of Thera (Santorin) Fouqué collected gas with 56 per cent of hydrogen, over water, in the presence of nitrogen and oxygen, and graded amounts both more and less have been collected at other volcanoes and by heating igneous rock *in vacuo*. Finally, the squirting up of Mauna Loa lava 500 feet vertically under gigantic banners of flame and cinnamon smoke cloud, for miles along a rift, so impresses a novice in Hawaii with combustible gas as prime mover that he wonders how the early observers could have been so blind to volatiles! (Brigham, 1909, quoting Green, 1873, p. 126).

REACTIONS OF VOLATILES

Such exothermal combinings as the water-gas reaction, and others releasing heat when fixed gases meet in vesicles, have been listed (Day and Shepherd, 1913; Daly, 1911b; Allen, 1922). How such gases are held in silicate solutions before they combine and without combining is subject for experiment. Partly they may be the product of cooling or pressure release of superheated magma (Niggli, 1919). That some of the gases burn in the oxygen of the air is shown by visible flames.

Three physical demonstrations of gas action are clear in Hawaii: (1) Gas is in solution in glass; (2) gas vesicles convectionally streaming and merging to make bubble fountains (pyromagma) are powerful stirring agents and heaters; and (3) gas escape, in accordance with laboratory principles (Shepherd, 1938, p. 340), leaves a cooler and stiffer mobile lava column, the epimagma, and this substance rises from indefinitely downward (hypomagma) and has great thrusting power. The stirring hastens crystallinity (Emerson, 1926), and the resultant differentiation in basalt makes aa lava that sprouts into arborescent forms when this substance freezes in the open without sufficient vitreous liquor to form a skin. When the sprouts break, a bouldery surface results. When crystallinity from stirring stiffens underground. a mobile paste moves onward, in filaments and sheets.

Interaction between volatiles, ground water, and cooler lavas produces all the solfataric features, and an important result is to concentrate sulphur, sulphides, selenium, sulphates, and the halogen salts in proximity to craters (Shepherd, 1924). This accounts in part for the excess of sulphur in volcanic emanations, as the crateral sublimates are repeatedly engulfed and, being volatile and soluble, are subject to assimilation in new eruptions. Hot sulphur banks and fumaroles near craters may provide a locus for new eruption, but ordinarily their gases differ from magmatic volatiles and are mingled with meteoric waters, with organic residues and concentrates of ancient eruption.

CONVECTION

This subject has been divided by Daly into thermal convection and "two-phase" (vesiculate and gas-free streams). He might have added viscosity-differentiate phase, solidification sinking of crusts, crystalline differentiation of epimagma, segregation of epimagma wells, and vertical streaming of epimagma filaments against friction of marginal selvage veneers. When we remember the sudden viscidifying of vesiculate glass on losing its light gases (hydrogen, etc.), and that the vesicles are preserved and refilled with heavier air or steam, it will be seen that pure vapor convection adds to the plexus of expansion, flotation of bubbles, and sinking that makes a lava column circulate. (*See* Part 4.)

When the powerful cascades of pyromagma pour down sinkholes they are still vesicular floods of stiffening glass. To simplify the issue we may consider the source wells bubbling with hydrogen that burns in the fountains, and a niagara of bubbles of steam plunges down a sinkhole. There is carried down in a self-adjusted well within the lava column itself the very vapor that by Goranson's (1931, p. 481) experiments goes into solution to lower the melting point. The multiple-phase convection truly stirs the lava column to profound depths, as Daly argues for the two-phase variety. This Bessemer furnace of rising hydrogen and sinking steam, stirring a slag to viscidify and crystallize as a congeries of lava tubes apportionate to the circulation, is itself the magma column. The tubes, rising wells, and sinkholes make of the column a self-constructing plastic tubular gas engine, itself rising when rising wells predominate in number and pressure, or sinking when cascade sinkholes achieve mastery, and the downflow of the convection carries the tubular piston with it. The stirred downflow liquid of diminished vapor pressure must end in crystallization of epimagma.

The thrusting power of this honey-comb, a lower-temperature mobile skeleton residual from what streams through it as high-temperature inflated glass, is distributed expansively through all its conduits from an indefinite distance downward and gives it "ascensive force" of vesicular expansion superadded to the deep and eternal rising of the hypomagma that underlies all. The hypomagma when unloaded changes to fluid glassy pyromagma charged with gas bubbles. What its own condition and ancestry is no one knows. That it rises through the ages, at a volcanic belt, is a postulate of what makes the belt volcanic. Given an age-long upward pressure, under cracks and edifices prone to periodic yielding, themselves filled or weighted by the outgush of the yieldings, and given the outgush due to dissolved gas sensitive to pressure release, you get the essentials for a volcano. Anything deeper is geonomic but not crateral.

Within the range of the phenomena of intrusion, an important question suggested by the epimagma of Kilauea is: To what extent does the transition from hypomagma through pyromagma to epimagma take place, in laccolithic and plutonic irruptions? From the subvesicular porphyries that the writer has studied in South Dakota, accompanied by intrusive breccias (Jaggar, 1900), to the granitoid rocks associated with diabases (Jaggar, 1898) that he has studied in Massachusetts, he finds no difficulty in imagining that magma is always initially basaltic and vitreous. If it is a glass surcharged with hydrogen and other elements, thought of as volatiles in the chemical laboratory, one may imagine magma as subject to rapid convectional stirring, under intrusive conditions, that stimulates solidification and gas loss but otherwise leaves no trace when the product has become wholly crystalline. Migmatitic and other plutonic contacts have no vitreous selvage because of gas emission, gas heating, gas stirring, and crystallization apportioned to pressure-solution-time like the main body. This would mean that every intrusion is a pyromagmatic derivative from a subjacent hypomagma, and in losing its gases with more or less assimilation of its contacts it reached stability in whatever chamber it fashioned for itself or diastrophism fashioned (Jaggar, 1900, p. 224, 282) for it. Dikes are well known that are composite or have zones of distinct texture up the middle, sills have gravity differentiates on their bottoms and their tops, and plutonic bodies have stoped-out inclusions, schlieren, and minute penetration into contact folia (at Schneeberg, Jaggar, 1895). It is of interest to search in the field at the cross sections of intrusive bodies, for scars of their discharged gas, traces of their complex convectional history, and derivation considered as epimagmatic crystallinity from primal glass.

In 1920 a group of distinguished and experienced geologists from four continents was taken through the southern aa lava fields of Mauna Loa and told that those piles of rusty black breccia covering hundreds of acres had been golden, liquid incandescent flows. All were incredulous. To them it was "basic breccia," "Surely this was a landslide," "You must mean it was explosive." When I told them I had seen that black riprap splashing over the grass like liquid porridge at bright orange heat as a syrup, they were respectful, but wholly puzzled.

Aa lava is epimagma congealed, after glassy pyromagma near the vent has boiled away its gases, stirred itself down the slope, rapidly crystallized, but with liquidity, and arboresced (Pl. 73d) on cooling to feldspar, augite, magnetite, and olivine. This astonishing differentiation in the field is of the essence of Hawaiian folklore, pahoehoe ropy, and aa scoriaceous: pahoehoe with vitreous skins, aa crystallized even on top; pahoehoe and aa both alike and crystalline in the ledge after cooling, beneath their different surfaces.

It is strange that Dana, Dutton, and the Vesuvian geologists never suspected that this conspicuous field difference of two basaltic types might be petrologically and physically of fundamental significance. One can imagine an old Hawaiian sage shown in the Black Hills of South Dakota the Harvey pegmatite and the Custer Peak smooth laccolithic porphyry. "Aa and pahoehoe," he would say. He would recognize epimagma and pyromagma. Possibly he would be partly right.

HYPOMAGMA

While discussing multiple phase convection, there is an important series of operations observed in Hawaii that may represent inversion of the molecular or atomic reactions that lead to the creation of the deep substance here called hypomagma. When a Mauma Loa crack opens to eruption, let us, for a convenient construct, imagine hypomagma to be Daly's vitreous substratum 60 kilometers down. For the purposes of a sun-derived earth imagine this to be the bottom of the outer terrestrial layers of superficial volcanic extravasation. Here, at least locally for the Hawaiian volcanic fissure system, from Hawaii Island to Midway Island there is a subjacent accumulation of hypomagma, at about the depth of the common local earthquakes (Jones, 1933b). Below this for more than 1200 kilometers there is the excessively hot siliceous mantle, of high incandescence and viscosity, transected along the general line of the Hawaiian belt by an igneous septum dividing the crust; an ignisept, an upright dike edgewise of what we may call subhypomagma guided to this position from the early days of the earth by the congealing and rupture that determined the primitive permanence of large volcanic fractures. This was a group of events long antecedent to the relatively later surface accumulations and crustal subsidences that determined what geologists call "permanence of continents."

We can imagine deep fissures along such lines as the Cape Verde and Andaman-Ladrone circles (Bellamy), the Nanking-Anadir line of centers of arcs (Pickering, 1907), the Cordilleran line of volcanism in North America, the Ecuador-Patagonia line in South America, the Iceland-Cape Verde line in the Atlantic, the Great Rift in Africa, and so forth. If we compare the primitive earth of this time with the moon, and consider the semicircles represented by the Sunda, Riukiu, Japan, Kurile, and Aleutian arcs, all volcanic, to be the traces of the wall cracks of primitive circular terrestrial maria or lava lakes, whose centers lay on a straight fracture similar in origin to the rift belts or bright lines on the moon, it is of interest to discover that these centers of varying radii do lie on a straight line. It is also of interest that the arcs are often truly circular and volcanic when plotted on a globe (Murray, 1945), and circularity is not a common geological result of tectonic processes, but volcanism on earth and moon tends to high circularity (Pls. 9, 10). The continental sides of all these circles are buried or destroyed, indicating that mediterranean processes covered primitive volcanism, or continental uplift broke the circles. A further corollary is that the oft-noted correlation of volcanoes with continental shore lines has nothing to do with ocean water but has much to do with the primitive geology of the earth that the deep oceans may reveal, if man once begins to explore the topography and petrology of the unknown 70 per cent of the rock surface of the globe. These and other circles, but of epicenters, are shown on Bellamy's (1936) map.

Returning to our primeval deep fissure under Hawaii filled with sub-hypomagma, it must narrow upward through the "crust" and at the moment be choked with congelation at Midway Island and chokingly eruptible at Hawaii Island. That magma wedgewise splits quasi-solid matter through all depths to 500 or 700 kilometers may be tentatively adopted as a hypothesis, for explaining deep earthquakes. It certainly is competent to split tensionally what behaves as a solid in the upper 60 kilometers. Before a Mauna Loa eruption it measurably creates progressive seismic centers 30, 17, and 5 kilometers below sea level directly under the point of eruption, (Volcano Letter, Oct.-Dec. 1935).

The eruption is a gush of oxidizing and sulphurous hydrogen and carbon gases, resembling a solar prominence, emitted along a straight crack, shooting up into the air flame and fume 1000 meters at 1350° or more (Jaggar, Thermal Gradient, 1917c). The oxidized mixture of hydrogen, carbon, sulphur, and chlorine is noxious in the extreme. The enormous inward pressure on the crack, of the mountain tumulus, is permissive, by the crack yielding, of only a limited eruption, apportionate to the damming action through the ages of the accumulation of ridge and earth shell, and adjusted to the relative restraint through the ages of internal solar matter.

I avoid as much as possible the words "cooling," "liquid," and "solid." Bethe and the physicists of atomism discover the sun growing hotter, and the radium specialists (Joly, 1926) permit storage and release through millions of years of terrestrial radioactivation. The modern physical laboratory activates numerous metals by application of electric energy (Lawrence, in Berkeley, 1940). Mere cooling of dead melts from heat without gases is a bygone conception. The sunspot volcanoid is localized, and the eruptive prominence from it is temporary; therefore the solar mantle is in some sense a crust, and the solar prominence is a localized release of hydrogen and the other volatiles. The "crust" of the sun is not a gas or a liquid, and obviously not solid. The sun's interior should contain different matter from its surface.

All these things may be true of Mauna Loa through a mantle of the same elements, within a more advanced and partially condensed atmosphere, the condensate ocean being a product of hydrogen that should be a godsend to the geodesist and geologist in preserving from erosion the pristine forms of the unknown two thirds of the earth surface. Solidification of the shell we may grant, but the gush of gas along a crack accompanying eruptive matter is measurably hotter from below upward and bubbles from a subterranean dike of silicate melt. A melt bubbling with gas, a rock squeezed to melting, a radiation heating to volcanism, a diastrophic flexure melt, or a diffusion heating by "volatiles" are progresses and evolutions, but they are not liquids or solids. A granitoid abyssal magma invading continental sediments, when it was active, was neither gaseous, liquid, nor solid; it was an evolving plexus, and when it "cooled" it continued evolution. In the quarry it is still "working."

The sequence in a Mauna Loa eruption that reveals this melt has never been observed with physical instruments, minute after minute, for the first hour of eruption. The polythermal, isobaric, saturation three-phase diagram cannot be plotted, as Niggli remarks. This precious hour expends the solar energy and leaves a relatively dead melt. Man has always come into the field afterward and wondered and worshipped at the degenerate products, literally expired as to gases, polluted with older surface chemistry, these products being called pumice or lapilli or lava flows. To the critical observer the act of congealing is full of hydration, oxidation, differential chilling, and snapping, consequent spoiling of surfaces, crystallization influenced topographically, and enclosure within tubular shells that sets up natural experiments in mineral synthesis.

PYROMAGMA

If there is one outstanding thing in a sudden Hawaiian eruption, it is the enormous expenditure of energy, and decay, during the first hour. Astronomers like Ellerman have compared it to an eruptive solar prominence. After this comes effervescent glass containing gases escaping from solution that froth it out into basaltic pumice. This piles up around the crack, and floods of the molten foam undercooled at 1150° C. escape in ribbon cascades down the mountain. To leeward or in an airplane above there is hardly any disagreeable gas. A quarter of a mile away these torrents change from ropy, wrinkling, and blanketed vitreous upper surfaces to a different type of crusting that starts with granules or nodes of black or rusty red crystalline sprouting and spreads through the mass to an appearance like a bed of hot coals. Oxidation, catalysis, and equilibrium shift are all in action. The higher wrinkling type of lava is pahoehoe, the lower sprouting type is aa, and so far as known the transition is occasioned by stirring and viscidifying that eliminates the glass, so that the residue is so saturated with the growth of crystallinity that no glassy matter remains to separate out on top. Except for pahoehoe skin, Hawaiian thin sections show no glassy groundmass.

EPIMAGMA

The upper pahoehoe of vitreous vesicular skin continues to emerge at the vent and to become less pumiceous. The skin of pahoehoe is a froth of pumice near the source. The escape of gas from solution, itself a stirring mechanism, probably continues in overturning the molecules of aa basalt to the lower end of an aa flow in juxtaposition with developing crystallization. The middle streams of the frontal fields of such aa are hot and liquid like the interior streams of skinned-over pahoehoe. In fact it is out from under the glassy-skinned fields of source lava that the aa liquid emerges. Moreover, down the middle of the actual stream beds banked with aa on either hand, rivers of the glassy-topped lava tend to overlap the aa fields. In other words the rapid liquid streams that are being transformed into the aphrolith are themselves dermolithic (Jaggar, 1917b) to the lower limit of separable glassy groundmass.

Meanwhile, with the loss of gas at the vent, and the stirring by gas fountaining within the vent, the same process of crystallization with loss of gas that has generated the differentiation between pahoehoe and aa on the outer mountain has generated the same differentiation between pyromagma and epimagma inside the rift down the subterranean shaft. If the energy of expanding and multiplying vesicles were insufficient to cause overflow, we would have only the crateral lava lake and multiple-phase convection, as discussed for Halemaumau (Part 4). With outflow continued, a less gassy slag is poured out, with decrease of gas stirring, and adjustment of the flowing melt to a vitreous casing that forms a skin over every lobe, pushing down the mountain by a mechanism of fanning deltas and protruding tentacles. This slower moving lava flow overtakes, or flows by the side of, the earlier rapid aa flows and carries with it an adjusted machinery of internal torrent in a tunnel and external shells that are dermolithic. These shells are porous heat insulators, the gases escaping from the liquid are heating agents, and the system of advancing tentacles seeking out the lowest ground selects the eventual location of the main tunnel. The resistance to flow of this tunnel structure becomes a brake adjusted to the volume supplied and the slope, so that the tentacle glass-blowing mechanism can prolong such a flow down various slopes for 40 or 50 miles and for months of flowing. The maintenance of even temperature, expansion, and pressure might be called adiabatic in a pahoehoe flow. There is local outflow rupture, gas melting, and wall freezing. The liquid, pouring onward inside the main tunnel, is adding crystalline matter to the walls of the tunnel and is competent, if stored anywhere in a large pool or reservoir, to lose its glass and take on the external characteristic of aphrolith or aa, if some breakage releases it to external flowing. There is here a nice balance of physical equilibrium between gas heat, pressure, and restraint of crystallization that imitates the deep mechanism. Many old pahoehoe tunnels, which have emptied themselves at the end of an eruption, are floored with lava of aa texture. If entirely drained, the floor may be secondary pahoehoe of gas-melted walls. Also a large pahoehoe pool, like the lake in the saddle between Mauna Kea and Mauna Loa in 1935, finding a sudden outlet down the steeper slope, may reach a place where it leaves glassy crust behind, owing to the sudden drainage, and so exhibit a renewed eruption where the rapidly stirred lava congeals with aphrolithic surfaces.

The eruptive phenomena from the beginning have been (1) hypomagmatic pressure, (2) opening of the crack, (3) effervescence, vesiculation, accumulation and reactions of gas, in the crack, (4) surface opening and escape of gas, and devesiculation, (5) burning of gas on contact with air, (6) deep effervescence and outflow, (7) sudden stiffening with loss of gases, (8) differentiation crystalline and vitreous, and (9) crystallization within the vent.

The end of an eruption is a reassertion of the mountain pressure against crystalline epimagma, a shrinkage by loss of gas of the internal hypomagma still vitreous to unknown depths, and an added weight of slag to the outside of the mountain.

CHEMICAL ELEMENTS

If we seek endothermic reactions in the ancestor of hypomagma or the subhypomagma that are a reversal of the happenings of the above list, it will be necessary to follow down some polythermal-solution curve involving hydrogen, helium, carbon, nitrogen, oxygen, aluminum, silicon, sulphur, and chlorine in the order of their atomic weights, and then of the remaining metals. Most of these are elements with low boiling points, and those with high boiling points like carbon and silicon become volatile in combination. Shepherd (1938, p. 317) writes

> "Reactions between mixtures of the following elements will be present: H_2, O_2, S_2, Cl_2, F_2 and Si, in greater or lesser degree. Perhaps the only gas reactions which have not been exploited heretofore are those involving Si, S_2, and H_2. We elsewhere pointed out that SiH_4 is a probable constituent of magmatic gases at the higher temperatures. Any place where free hydrogen and a silicate arc in contact at temperatures around 1100° will show some SiH_4 formation. Of even greater significance are the silicon sulphides which Hempel believed he has shown to be present in Vesuvian lava. These sulphides form with great ease whenever sulphur and silica are heated to about 1100° under reducing conditions; the reaction is a commercial one used in the purification of bauxite. At some depth therefore silicon sulphide may be expected, and a slow but continuous removal of silicon from depth toward the surface may be expected to have been under way from the beginning. While we are not used to considering silicon compounds as 'volatiles', they evidently must be so treated". Even unmixed, the boiling point of silicon is only 2600° and of aluminum 1800°.

Our physicists are vaporizing iron and carbon every day, the successors of Onnes and Dewar are solidifying and crystallizing hydrogen and chlorine through liquid stages by pressure and lowering temperature, and Bridgman (1939) and his colleagues are making critical changes of state by high pressures. Neither temperatures nor pressures nor apparatus to restrain gas in the laboratory (50,000 atmospheres equals only 100 miles of rock) can come anywhere near what the earth's interior can do, and in solar research only by electric energy can the stellar forces be somewhat imitated in miniature. The long train of dispute about the interior earth on inadequate data by Kelvin, Prestwich, Delaunay, Ritter, Arrhenius, Woodward, and the like is so completely in flux today and in such disagreement that it seems unwise to follow a "school of thought" based on anything but facts from the field.

The maximum acceleration of gravity would be at 610 miles depth, not far beyond the deepest recorded earthquakes. At that depth the pressure would be 354,000 atmospheres, or over 5 million pounds per square inch. At the earth's center the pressure would be 9 times greater, or more than 60 times the greatest achievements of the laboratory. There are no tables of critical change in elements at these pressures. Without extrapolation on the meager data of human drill holes, it appears that the temperatures are beyond the critical temperatures of all known substances, that the outer shells of earth restrain juvenile hydrogen and helium inside, that juvenile oxygen comes forth in carbon dioxide and water vapor, and that the centrosphere is atomic or subatomic.

PHYSICAL PROPERTIES OF GASES

One of the neglects of the comparisons of the late H. S. Washington between earth elements and meteorites is his omission of the gas constituents other than oxygen. Nitrogen is omitted from elemental rock and meteorite analyses, averaged or otherwise, although granite, basalt, and meteorites give off nitrogen when heated, and liquid nitrogen weighs 0.8 as much as water. In the index to Clarke and Washington's *Composition of the earth's crust* there is no listing of either hydrogen or nitrogen. It is well known that liquid inclusions, supposedly carbonic acid, are found in igneous rocks. This neglect of nitrogen is shown in the last column of Table 10, which is assembled from several sources (Hodgman, 1936; Clarke and Washington, 1924; Washington, 1925).

TABLE 10.—*Common elements in various orders of increase*

Order of boiling points		Order of atomic weights		Order of average outer rock, sea and air combined (In weight %)		Order of average igneous land rock	
H	−253° C.	H	1.0078	F	.027	N†	not computed
N	−196	C	12.00	N*	.030	F	.030
F	−187	N	14.008	S	.048	C	.032
O	−183	O	16.00	Mn	.08	Cl	.048
Cl	−35	F	19.00	C	.087	S	.052
P	280	Na	22.997	P	.12	Mn	.10
S	445	Mg	24.32	Cl	.188	H	.13
K	760	Al	26.97	Ti	.58	P	.13
Na	880	Si	28.06	H	.88	Ti	.63
Mg	1110	P	31.02	Mg	1.94	Mg	2.09
Ca	1170	S	32.06	K	2.40	K	2.60
Al	1800	Cl	35.457	Na	2.64	Na	2.85
Mn	1900	K	39.096	Ca	3.39	Ca	3.63
Si	2600	Ca	40.08	Fe	4.70	Fe	5.01
Fe	3000	Ti	47.90	Al	7.51	Al	8.13
Ti	3000	Mn	54.93	Si	25.75	Si	27.72
C	4200	Fe	55.84	O	49.52	O	46.59

* Includes A, He, etc. (Washington).

† N, A, He, Ne, Xe, Kr not computed (Washington).

Among boiling points and atomic weights there is some correspondence, but, in boiling points, carbon, the solid, departs widely from its nuclear partner nitrogen. The volatiles sulphur and chlorine move down among the heavy atoms in going from column 1 to column 2. Proceeding to column 3, inclusive of lithosphere, hydrosphere, and atmosphere, the volatiles excepting oxygen remain near the top in small amounts, while at the bottom oxygen is captured for the maximum. As the igneous rocks occupy 95 per cent of the crust, and they are a gas-tight rust of oxides on a globe supposedly metallic, it is easy to see why columns 3 and 4 keep together in their lower halves. It is apparent why C, Cl, and H should be more abundant in the ocean-air column, but not why Ca, Al, and Si should be less if all the sediments are included to the depths of sea and continent.

Notable is the omission of nitrogen and all the noble gases when the amounts of these obtained by outgassing (Shepherd, 1928) are considerable, and they are constant juvenile ingredients of basaltic magma (Jaggar, 1940), about 24 per cent of the surface gas. They occur in amounts greater than F, Cl, S, and H, all of which are in Washington's rock analysis table. The assumption of the chemist was that N is atmospheric, and the gravimetric method gives it no place in competition with the heavier atoms. Verhoogen (1939a) in the flames of Nyamlagira of 1938 finds spectroscopic bands of nitrogen of high energy, which make it possible "that much of the nitrogen in volcanic gases is purely magmatic" and not atmospheric. To the volcanologist thinking in terms of solar matter compressed, the magmatic ignisepta of the outer earth are not included at all in Washington's analyses. Before considering Washington's earth shells, we may picture what physicists know about the density of gases liquefied and solidified, without implying an earth analogy.

TABLE 11.—*Solidified common gases in the order of increase of their densities*

	Gm./cc. solid density	Gm./cc. liquid density	Gm./cc. 760 mm. gas density 0°C.	Temperature C. liquid boils	Temperature C. solid
H	0.076	0.070	0.00009	−253	−260
H_2O	0.917	1.000	0.0000048	+100	0.0
N	1.03	0.804	0.0013	−196	−253*
F	1.30	1.11	0.0017	−187	−253*
O	1.41	1.14	0.0014	−183	−253*
CO_2	1.53	1.19	0.0019	−60	−79
A	1.65	1.41	0.0017	−187	−233
C	1.90	1.56	0.0032	−34	−102

* Chilled in liquid hydrogen.

Table 11 assembles solidified common magmatic gases as they are known to the laboratory, with the appurtenant solid, liquid, and gaseous densities and temperatures, following Kamerlingh Onnes, Dewar, and others (Dewar, 1911; Hodgman, 1936).

It is here shown that hydrogen can be made to solidify with density comparable to one sixth that of metallic lithium, while ice compares to ozokerite and paraffine; that nitrogen, fluorine, and oxygen may acquire by pressure and chilling the specific gravity of amber, coal, ebony, sulphates, soda, and haloids; and that carbonic acid, argon, and chlorine may when solid be comparable in mass to ferrous sulphate, alum, and borax. The liquid densities range from one tenth that of ether to that of strong sulphuric acid.

KILAUEA GASEOUS ELEMENTS

The writer has published (1940) a treatment of 26 Hawaiian vacuum-tube collections of live lava gas, in series, making the ideal gas of a perfect collection close to the surface at Kilauea constituted as follows (volume per cents at 1200° and one atmosphere pressure):

CO_2	44.00	A	0.66
CO	3.50	SO_2	20.00
H_2	3.80	S_2	4.00
N_2	24.04		
			100.00

The sulphur and nitrogen of this analysis are excessive for the deep region, where they would be replaced by hydrogen and carbon dioxide. The water gas reaction is dominant. The excess nitrogen is from air, and excess sulphur from fumed rock.

TABLE 12.—*Volume analysis, 26 vacuum tubes Kilauea gases*

Specimen	C	N_2	H_2	A	S_2	Cl_2	O_2	Quality of Collection
J.6	0.31	20.01	8.68	0.00	0.05	0.03	70.90	P*
J.12	0.41	0.68	10.94	0.05	0.33	0.03	87.54	P
S.10	0.60	2.44	10.43	0.39	3.56	1.34	81.24	P
S.6	0.89	3.50	10.25	0.07	3.18	0.00	82.10	P
ML.1	1.06	16.80	8.44	0.58	1.44	0.00	71.67	P
S.1	1.17	25.22	11.83	udt	0.78	udt	62.98	F
J.2	1.58	7.92	8.40	udt	3.35	4.08	74.72	P
ML.2	1.83	15.39	7.55	0.42	4.16	0.00	70.58	P
J.3	1.90	2.37	9.14	0.56	3.83	1.11	81.18	P
J.4	1.91	2.33	9.68	0.00	2.21	0.62	83.24	P
S.9	2.62	8.92	8.53	0.29	10.89	1.01	68.17	G
S.5	3.08	10.47	8.77	0.00	7.68	0.00	69.99	E
J.15	3.20	6.20	8.37	0.16	3.78	0.10	78.17	F
J.17	3.33	1.29	9.45	0.04	3.48	0.05	82.33	G
J.14	4.24	2.91	5.77	0.00	2.34	0.00	84.72	F
S.8	4.35	0.87	9.10	0.14	3.98	0.00	81.54	G
J.10	4.53	15.03	5.79	0.21	8.27	0.03	66.12	E
S.4	4.71	—	10.09	0.51	8.61	0.02	79.16	P
J.13	4.88	3.35	8.51	0.66	5.04	0.10	78.05	E
S.7	4.97	5.88	7.94	0.18	5.95	0.25	74.77	E
S.2	5.05	37.84	5.66	udt	2.25	udt	49.18	E
J.18	5.11	4.50	7.75	0.12	6.92	0.13	75.47	E
J.11	5.96	4.13	7.21	0.31	6.19	0.00	76.26	E
J.16	6.43	3.11	8.08	0.08	5.43	0.08	76.78	E
S.3	9.74	12.88	3.57	0.45	16.72	0.17	56.02	E
J.8	13.63	2.41	4.53	0.14	5.78	0.04	73.46	E

*P = poor; F = fair; G = good; E = excellent.

The 26 analyses are exhibited by elements in Table 12. The specimen names follow Shepherd (1938), and the order of arrangement is by increase of carbon, which follows remarkably increase of excellence (E) of conditions, of field, of manipulation, of analysis, and of domination of the inflammable ingredients.

In the order of increasing excellence of collection, carbon increases because CO_2 and CO increase; nitrogen is erratic because convection has carried down air and oxidized the combustible gases to H_2O, CO_2, and SO_2; hydrogen decreases with oxygen because water decreases in the good collections; argon and sulphur somewhat increase as volcanic ingredients, though much of the sulphur is derived from crateral concentrates; chlorine is a marine water contamination dominant in the poor hydrous specimens, and decreasing; and finally oxygen, while decreasing with the water content, holds its own because CO_2, CO, and SO_2 increase in the excellent collections. Water vapor is in great excess in all but the most exceptionally volcanic samples, as product of the exhaustion of hydrogen by air, CO_2, and SO_2; all these reactions raise the lava temperatures. Exceptional specimens have been collected with only 10 to 17 per cent water. The range of water from 97 per cent (poor) to 17 per cent (excellent) produced a curve with water vanishing, and the end member is the ideal gas above mentioned.

Thus hydrogen and carbon dioxide are dominant in the depths, their reaction being slow and nonexplosive. N_2, S_2, and A are volcanic but quantitatively less. H_2O, SO_3, and Cl_2 are secondary. At Halemaumau the quiet water-gas reaction progresses at the source wells; air flaming acts violently at the grottoes.

CONDENSED GASES NEGLECTED

It is unfortunate that all analyses of what petrologists call rocks are expressed, not as the elements, but as combinations with oxygen. Thus in these pages, and following so distinguished a physicist as Arrhenius (1900; 1903; 1908) in considering the interior matter of the earth to have a solar quality, we are unable so to inspect tables of those crystalline skeletons of former magma as to see at once how much oxygen or iron exists in a basalt or a granite. Washington's (1925) analyses (Table 13) by elements are weight proportions for shells of an imaginary earth in terms of meteoritic analogy and average rocks; a Hawaiian gas analysis (Shepherd, 1938) is added, computed by elements, volumes at 1200° C., and at atmospheric pressure. The achondrite comes nearest to a Hawaiian basalt. The iron-core doctrine is supposed to be reinforced by spectroscopic analysis of the atmosphere of the sun, which with iron meteorites makes cosmic analogy for the commonness of iron and nickel, (Washington, 1925). The fallacy is in the word "atmosphere." With iron common on the outside of earth and sun, and meteoritic material representing outside solidified layers of disrupted cosmic bodies, it seems probable the inside of all three contains many of the 62 heavier elements that are relatively rare outside. These, compressed and ionic at completely dissociating high temperatures, are presumed to be gaseous on disruption and otherwise remain unperceived and indeterminate in solar-system cores. A disrupted fluid core would not make meteoritic fragments, and seismologists agree that the earth core is fluid.

In the shells based on meteorites Washington pays no attention to H, N, F, Cl, Br, A, Ne, He, or Kr. These are given no place in an inner earth of tens of thousands of tons pressure per square inch, though they abound at 2 to 40 volumes, in crustal dead rock and dead meteorites. The gases are the more compressible elements and in their known solid forms have an average density of about 1.23. The rare xenon has specific gravity of 3.06 at $-109°$C. and is an atmospheric gas. Comparing the ratios of their densities above as gases and solids, and remembering we know petrologically the liquefaction of gaseous inclusions in minerals and that all substances above their critical temperatures must behave as vapors or ions, it becomes possible to envisage the centrosphere of unknown boundaries, constituted of nuclei and protons, as a kinetic organism of increasing density inward, with internal motions of reaction cycles from center outward, to fractional molecular distillation in the ignisepta and intrusive bodies.

The report of the interpretation of the surface of the sun by Bethe (1939) of Cornell University accepted by many modern physicists and astronomers (Gamow, 1939;

TABLE 13.—*Composition of earth in terms of elements (Clarke and Washington)*

	Siderite central core	Pallasite (iron-olivine)	Chondrodite (olivine-enstatite-iron)	Achondrite (hypersthene-olivine peridotite)	Basalt (Daly lower shell)	Whole earth
Fe	90.67	51.52	21.55	13.51	8.86	39.76
Ni	8.50	4.25	1.57	0.33		3.16
Co	0.59	0.30	0.07	0.04		0.23
O		21.11	37.10	42.05	44.24	27.71
Si		9.35	18.34	23.00	23.24	14.53
Al			1.55	3.26	8.46	1.79
Mg		13.36	13.88	10.91	3.78	8.69
Ca			1.72	5.09	6.51	2.52
Na			0.65	0.50	2.35	0.39
K			0.14	0.22	1.28	0.14
Ti					0.83	0.02
Cr			0.34	0.31	0.10	0.20
Mn				0.18	0.25	0.07
S	0.04	0.01	1.82	0.54	0.10	0.64
P	0.17	0.09	0.12	0.06	0.20	0.11
C	0.03	0.01	0.15			

	Average igneous rock (continental shell)	Ocean (weight %)	Atmosphere (volume)	Kilauea gas (volume 1917) spec. S2
Fe	5.01			
Ni	0.02			
O	46.59	85.79	20.99	49.18
Si	27.72			
Al	8.13			
Mg	2.09	0.14		
Ca	3.63	0.05		
Na	2.85	1.14		
K	2.60	0.04		
Ti	0.63			
Cr	0.04			
Mn	0.10			
S	0.05	0.09		2.25
P	0.13			
C	0.09	0.002	0.03 CO_2	5.05
H	0.13	10.67	0.01	5.66
Cl	0.05	2.07		udt
Br		0.008		
N			78.03	37.84
A			0.94	udt
Ne			0.00123	
He			0.0004	
Kr			0.00005	
	0.34 (misc)		Xe 0.000006	

Shapley, 1945, p. 510) is that nuclear reactions are causing transformations of hydrogen with carbon of atomic weight 12 to produce nitrogen of atomic weight 13, which by its instability goes over to carbon of that atomic weight with release of an electric charge. This again unites with hydrogen to produce nitrogen of atomic weight 14, which gathers up more hydrogen to yield oxygen of atomic weight 15. This is again unstable and in releasing an electric charge produces nitrogen of that higher atomic weight. Again hydrogen is added, with carbon and helium as the products, helium being the dead refuse of the world of transmutation of the elements. Carbon^{12} and nitrogen^{14} nuclei act as catalysts with protons, in carbon-nitrogen reaction cycles. Substituting electric energy for heat, three of the steps have been imitated in the laboratory at Cornell, one by two physicists at Cambridge University, and recently Bethe and a colleague have executed synthetically the fifth and sixth stages in the process. The cycle on the sun is computed to require 6,500,000 years, there is enough hydrogen to last some thousands of millions of years, and enough carbon-nitrogen reaction cycles are constantly in operation to emit radiant energy corresponding to a surface temperature of 15,000,000°C., and an internal temperature computed as 20 million degrees. No volcanologist can read this story of these particular elements and fail to note that it accords with the analogies of volcano process as we know them, with the volcanic products hydrosphere and atmosphere and life, and with the imaginable internal processes of the earth for guidance of future experiment. It is stimulating, as shown in Part 5, that Hawaiian and solar cycles have indicated agreement in intervals.

ROCK SHELL

The volcano surmounts a world of rock geology beneath it. This shell of the globe has furnished collections of crystallized or amorphous igneous matter to the petrologist, from possibly 15 per cent of the earth's surface; the rest is sedimentary matter and bodies of water, the rock bottom of which no geologist has ever core drilled for thermal gradients and lithology. Most of the rock bottom of the true oceans, the large ice fields, the great lakes and flood plains, and the enormous sedimentary tracts of upraised Mediterranean sediment over vast areas of all continents has never been explored by drilling. Therefore geology is a detective science that has barely begun to tap the fountain of knowledge about the geography and geophysics of igneous rock. When we hear of a rock carbide, a semimetallic basalt, a rock containing radioactive elements, or a location of anomalous heat, gravity, or magnetism, it is well to bear in mind that 85 per cent of the earth's igneous shell is totally unknown, and the nuclear activation of its metals may extend far beyond pitchblende and radium. The earth like the sun may periodically be getting hotter (Joly, 1926).

Speculative theorists imagine a shell of defined thickness ranging in depth from 30 miles to 1000 miles, overlying some heavier substance below, which in turn overlies a still heavier spheroid of metal presumed to be liquid. All this classification of imaginary shells is based upon an imagined cosmogonic history, a very few surface physical measurements, and an elaborate science of earthquake echoes dependent on supposed homogeneities and textural elasticities, in averages so broad as to bear little resemblance to geological facts of the surface.

For volcanology the rock mantle is of interest because the surface of the earth is ruptured and is measurably rupturing at places of groups of volcanoes. The shells of theoretical seismology and cosmology, the debatable theorizings of isostasy, and the statistical generalizations of limited continental and island petrology play small part in volcanology of the broad sea bottoms.

On the other hand the scientific need for empirical data by measurement in the field, over all the earth, including the sea bottoms, is real. The methods of geophysical and oceanographic prospecting are of first importance, where a map and section and specimen result and exhibit data of experimental proof. The seismographs at three volcano stations can locate an earthquake centrum in depth. Defining the characters of an alleged "epicenter" is quite a different matter, unless it is explored geographically and instrumentally. If the actual point of origin of an earthquake is justifiably located 400 miles or 40 miles underground, that place should be considered rock shell, if other earthquakes are made by breaks in the rock shell. The interest of a volcano observatory is in magma motion and measured magma change underground. It is interested in speculation provable experimentally.

As geophysical instruments may locate deep magma in motion, the volcano laboratory is interested in the shell of the earth wherever motion or physical change can be located experimentally. Its construct, or model, or imagined mechanism, must harmonize with known physical fact about magma observed at the surface. The dike that underlies a volcano contains materials like the very limited intrusives known to geological experience (from which 80 per cent of earth's surface must be excluded) and like the very limited group of volatiles known only optically on the surface of the sun and found partly condensed on the surface of the earth. Daly has been at great pains to show what a poor conductor of heat rock is. The earth may have an insulating layer against radiations from subatomic core, but radiations may yet be located. What little we know of the surface rock of the globe shows it to be heterogeneous in structure, composition, and relief. It seems likely then, if there is any finite rock shell, that it is heterogeneous in thickness, in structure, in rupture, in composition, and in the relief of its bottom surfaces, that it is very thick and rigid, that it is a very poor heat conductor and a good gas insulator especially at high temperatures, and that the matter down beyond is solar in quality, hot, and in entirely unknown condition with reference to ordinary experience, unless we include our instrumental experience of the physical condition of the sun.

An earth crust as thick as that postulated by Wiechert, 1000 miles, over an earth center of solar matter like that postulated by Arrhenius, with considerable irregularities to the bottom surfaces, brought about by a volcanic history connected with the permanence of volcanic rifts and of ocean basins, might possess a rigidity and a variety of discontinuities, in the shell itself, to give some basis for the current interpretations and discrepancies of seismometric geophysics. Seismologic theory should provide for thick vertical partitions.

PRESSURE MECHANISM

The experience of volcanism in Hawaii requires a steady upward pressure in magma. This was recognized by Dana, who called it the "ascensive force." Parenthetically it may be pointed out that, if the surface of the globe is everywhere underlain by igneous magma, this expansive pressure becomes an outward stress as a world-wide potential. It might be thought of as the earth's magmatic field, in some way controlled by the thermal and kinetic condition of the centrosphere. If living intrusives are numerous, gas-active, and rapidly turbulent, supplied from a centrosphere engaged in nuclear reactions, this motion may account for microseisms as modified by barometric change, and the thermal periods of revolution of geologic history may have resources quite other than radium. The kinship with sun spots may be direct.

Observation of the Hawaiian volcanoes leads to belief in a sensitive pressure control on the rising magma. All evidence favors the supposition that this control is by weight of the edifice that the overflows build. The shift of action from one vent to another indicates alternation between adjacent volcanoes and structural sequence along rifts, as though splitting and sealing accompanied the migration of magma in a dike. This is probably parallel in miniature to ignisepta through the ages. The 11-year cycle appears to be an adjustment to gravitative pressure of the larger deep structural fracture; the incidents of the cycle are controlled by path of least resistance among the several volcanoes. Finally, the mechanism of breathing appears to be tidal, and ultimately a gas release by means of the rock tide, where the lava underground is in some nice adjustment to its dissolved gases. The sensitivity may be far beyond anything known to physics, because of unknown conditions. As soon as the trigger is pulled, and effervescence starts, the separate columns of different vents show that they are connected underground by way of adjacent fault fissures; the wedging open of one such fissure and the foaming up of the melt will itself release pressure on some other member and lead to a sequent eruption or subsidence. By rock tide we mean any cosmical pressure change on the spheroid.

There are thus two pressures, the fundamental one always present, and the secondary one, local to the yielding of the edifices; the edifice may be large or small. There is nothing in the Hawaiian volcanoes that suggests that so-called "explosive" eruption has any connection with juvenile gases dissolved in magma. Everything indicates that such a rare occurrence is phreatic and associated with lowered magma.

EARTHQUAKE CENTRUM

The experience of Hawaiian seismographs reveals earthquakes more intense when lava is low (Pl. 75), earthquakes frequent when it is rising, and earthquakes still more frequent when it is lowering (Jaggar, 1917, Mauna Loa). The more extensive quakes, felt uniformly over a wide area, are the deeper ones. Those highly localized about a crater occur at a variety of depths and at adjacent fault surfaces. Some cases that show consistent results indicate a rising dike, acting as a wedge to split open its chasm at progressively higher levels. In other cases, earthquakes are occasioned by the plug of a crater bottom suddenly yielding, when bearing with all its weight to wedge open the fault crack that passes through the crater. Probably both these processes act together; the rising lava makes a shock in wedging open the fault; the slipping crater plug makes a shock and holds the fissure open. In combination they withdraw pressure from magma.

SUBMARINE OUTFLOW AND RADIAL RIFT

The experience of all students of Hawaiian geology—and this applies also to Japan, Tonga, Italy, and Iceland—shows radial cracks from crater to shore and concentric cracks about the sink or caldera. The two radial rifts are commonly a single fault athwart the shield or dome that bends in plan at the crater. It may curve in plan from the crater outward. If centrally bent, its two radii bound a sector of the shield. The sector with its point at the crateral center of the dome acts like a lid to be thrust up by subcrateral magma. Such a lid hinges along a concentric fracture somewhere down the mountain flank. All this "sectoral-break-and-hinging-lid" has been seen in miniature at pits and spatter cones.

The domes of shore volcanoes extend out far beneath the ocean. The radial rift belt seeming to end at the shore cannot possibly do so. The rift belt vomits out flank lava flows above sea level. It cannot possibly fail to do so below sea level, but such outflows do not show. When hundreds of superficial lava flows lie along single rifts, say northeast and south from the central craters of such volcanoes as Etna and Mauna Loa, there must be other submerged flows under the sea. The correlated phenomena on land, crateral or seismical, of submarine outpouring must have happened, with outflow unperceived, many times in Hawaii and Italy. No supramarine smoke or steam or boiling would appear over deep water. A flank surface outflow in Hawaii is quiet and free from felt earthquakes or explosions or noises. Only twice has submarine boiling been noticed. An eruption in very shallow water floated up pumice in 1877 in Kealakekua bay west of Mauna Loa, and a preceding splitting of rock surface down the mountain was noted by cattlemen, and summit crater lavas were drained. In 1906 submarine pumice ejection is reported by Sapper (Padang, 1938, p. 95) between Laysan and Kauai.

The 1924 explosions of Halemaumau have been erroneously described (Daly, 1938a, p. 129) as the melting out of a plug of frozen lava lake and accumulated debris of years, through the slow rise of fluxing volcanic gas. What really happened was breakage and sinking of the plug into an emptied void. The glowing lava lowering in a bottom well was splashing 15 days before the crisis, and sinking incandescent paste was present 2 days before the first ejections. A great sea of lava noxious with magmatic gases had occupied the whole pit 3 months before, and both lava and gas disappeared. The engulfment was a direct withdrawal of liquid lava, and the steam explosions were phreatic and almost devoid of lava gas. The whole process was a visible splitting of the east rift to sea level and below, and the withdrawn lava either drained seaward or plunged down through the crust of the earth. The latter alternative seems unlikely, as there is 18,000 feet of submarine height to the slope of the mountain, with rift leading out to sea. Siphoning of heavy slag that weighs three times as much as water is normal, with escape along the crack behind rift blocks; these had been slipping seaward at right angles to the rift belt since 1919. The cracks had so opened through geologic ages, and their effusion product had built the submarine mountain.

Such is the submarine outflow and radial rift mechanism, and as a conception in structural geology this will bear extension to hundreds of volcanoes to account for lost magma and inflow of ground water. Unseen submarine lava flow may have made the culminating crises in Sumbawa, Krakatoa, Vesuvius in A.D. 79, White Island, Iwojima, and Bogoslof. Observed flank-rift faulting and outflow made Sakurajima "explode." Unseen submarine lava flow from Oshima may have precipitated the collapse of Sagami Bay, which was the center of the Tokyo earthquake. Finally, out in very deep water opposite the east rift of Hawaii, the old chart shows rocky ground, in 1700 and 2600 fathoms, "lava," and "volcanic rock fragments." The sounding and collecting detail of these submarine footslopes of the great seashore volcanoes and a submarine map of lava flows promise discovery that will help complete our knowledge of volcanism and promise a method that will really explore the geology of ocean basins.

GROUNDWATER IN VOLCANISM

With regard to sea water, there was almost no chlorine in the Kilauea 1924 steam. There are always crusted white deposits of salt when a surface lava flow into the ocean confines and explodes shoreline salt water. This has been repeatedly seen in Hawaii. Lowering of crateral lava to a submarine outlet along a rift, with collapse of central crater for partial plugging, does not admit sea water. The salt water under a fissured oceanic island is covered with an outward-draining water table of fresh water. When lava is withdrawn from a collapsing shaft, the water table pressure makes inrushing springs. If the withdrawal is occasioned by deep magma pressure and wedge tension splitting and widening the dike fissure out to sea, then the opening of the crack seaward that lets the lava out will on the landward end of the same crack let the ground water in. In other words an emptied hot dike fissure is filled with a rush of ground water directly under a debris-plugged crater well. The result is a steam-boiler starting rhythmic blasts up through the plug, which will continue until the cold water conquers the heat supply or the lava ceases outflow by loss of its gases, backs up, and dams off the subcrateral springs.

Different steam-blast eruptions have illustrated both these processes. In Tarawera, Bandaisan, and Soufrière, the water apparently conquered the heat. In Tarumai, Pelée, and Kilauea the lava rose and shut off the water. In Katmai crater apparently the water won, but in the famous "Valley" the lava of Novarupta won, and its extension as dikes gradually solidfied, after solfataric geyser action with ground water made the "ten thousand smokes" for some years.

INTRUSION UNDER VOLCANOES

The tension fissure opening for dikes as illustrated by the new fracture, gaping open downward, athwart Kilauea November 28, 1919, the fracture coming together as a hair crack at the surface by the inward pressure of the mountain, is paralleled by Daly's dike photograph that wedges out upward (Daly, 1938a, Fig. 9, inverted by erratum). All dikes that widen downward have to enlarge a topographic prominence or accompany chordal extension of the crust, either aggressively or by upward tectonic suction. If a volcano is so extended along a pre-existing rift belt, the presumption is that the new dike has been aggressive, as the vacuum pressure by contraction cracks necessary for upward suction of such a heavy fluid seems improbable.

There may be deeper dike swarms where contraction of the crust makes vertical tension cracks over eruptible magma that helps to fill the fissures. The seismic accompaniment in 1919 at Kilauea and 1935 at Mauna Loa indicated dike rupture as an earthquake maker, and the outflow sequences that opened the surface hair cracks implied a tilting seaward of the fault blocks along the rift to absorb the tumefaction.

This mechanism of tumefaction in surface volcanoes may affect concentric ring-dikes (Anderson diagram, *in* Bailey, 1924, Volcano Letter, No. 318) and prepares the ground for circular engulfment.

A paradoxical but real result of sudden yielding to wedge tension of crack under crater is lava lowering in crater; the lava rushes into the extended crack and robs the crater pit, resulting in frothing of lava from release of pressure. The lowering in the pit is followed by rapid rising (Kilauea, December 1919).

This concept in physical volcanology suggests that time sequences of rising and lowering in a pit like Halemaumau may be rhythms superposed on steady rising by echelon yielding of the edifice. Intrusion alternates with upwelling. The volcanologist witnesses intrusion, his seismograph locates it sometimes in considerable depth, and experiment is guided toward geophysical prospecting of the ocean floor for the topography, the depth of sediment, and the igneous rock.

The magnificent revelation of orderly sequence in the Hawaiian volcanic system 1914–1933 was:

		Elevation above sea level *Feet*
1914	Mauna Loa crateral inflow	13,100
1916–1919	Mauna Loa outflows	8000
1919–21	Kilauea crateral outflow	3700
1920–23	Kilauea flank outflows	2700
1924 April	Kilauea flank splitting at	sea level
1924 May–June	Kilauea flank outflow?	below sea level
1924 July	Backing up to Kilauea crateral inflow	2400
1926	Backing up or maintenance of Mauna Loa crateral inflow and outflow	13,000–7,500
1933	Mauna Loa crateral inflow	13,200

Wedge tension of lava in a swarm of dikes actuated the fault blocks in steps from the summit crater of Mauna Loa to the Kilauea sea cliffs. Progressively the rifts opened by echelon yielding of the edifice. Some were adjusted to intrusion only. In the 1914–1924 cycle the southwest Mauna Loa rift yielded to extrusion twice, the southwest Kilauea rift once, the east Kilauea rift twice, and then it opened seaward. Clogged after viscidifying under the sea, the magma made Kilauea inflow, next Mauna Loa inflow and outflow, and finally Mauna Loa crateral filling. This filled the "dike" reservoirs for completing the 1925–1935 cycle by 1934 inflow at Kilauea and 1935 outflow at Mauna Loa. Then came long repose. All active volcanoes continuously have intrusion in progress under them, interpretable with pointer readings.

THE UNKNOWN

The physicist will be impatient at references to the unknown. In this I am backed by Major C. E. Dutton, "It is a simple appeal to a mystery." Since Dutton's day the volcanic mysteries of solution, gas, radioactivity, transfusion, batholiths, deep earthquakes, exothermic heat, and his own seismicity and isostasy have been illumined by his appeal. In Hawaii we have measured lava products, volatiles, heat, crateral sympathy, flames, gas reactions, tiltings, tides, viscosities, soundings, crateral elevation, subsidence, and engulfment; we have observed cracks opening to sea level, pure steam in phreatic explosion, and long- and short-term periodicity and we have bored into a hot crater for thermometry; and we have perceived hypomagma, hypocenters, reactions between gas and lava, ground water, intrusions, submarine outflow, cycles, and correlation with sunspots. From measurement to observation and experiment, and thence to perception, it is reasonable to proceed to deep constructs, as Dutton did, and there to evaluate the unknown. The unknown of today is reality tomorrow when we face the facts of scale and accessibility and start measurement in the field of dynamical geology.

PART 7.—SUMMARY AND CONCLUSIONS

SUMMARY

Detailed description of the 87 plates is printed with each plate and recommended for the reader's perusal. The 1913 diary of Kilauea observations developed the problems of effervescence, gas, seismometry, differentiation, and convection. The narrative of 26 years of volcanic process exhibited Kilauea in relation to Mauna Loa, Hualalai, and Mauna Kea. The diagrams exhibit seasonal tides; the facts led out to sea floor, and measurement of tilt and ground movement led downward to intrusion. These features were accented by the journal of the phreatic eruption of 1924.

The facts show Halemaumau to be a glass-blowing system, with crystallization differentiating aa from pahoehoe as internal textures. Hypomagma the deep gas-charged glass, pyromagma its vitreous foam, and epimagma its crystallitic derivative make the tripartite lava column. Hypomagma rises through the ages; pyromagma froths up and heats by fracturing release; epimagma viscidifies by loss of volatiles to a mobile container encasing the pyromagma. The number of gas fountains and rise of temperature vary with volume of pyromagma. The height of the crateral lava column is measured on epimagma, and the nature and contact of the thrust of hypomagma beneath epimagma are problematical.

Dana's conception of permeating subterranean vadose water and absence of carbon dioxide and high seismicity in Hawaii, as characteristics of volcanoes, is contrasted with recent gas collecting and seismometry that recognizes gas-charged magma making the water-gas reaction and exerting wedge tension seismically against weight of accumulation. The result is cycles, influenced by luni-solar stresses.

The definitions that were deferred from the first page of Part 2 include common words like "activity" and "eruption" which are no more definable without experience than are "volcano" and "lava". If lava is hypomagma under the earth's surface, no one has ever seen it. If magma is solar matter in unknown condition, why define it? To one observer a volcano is a hill, to another a crack. To a sea captain a smoking island is "active," to the experienced volcanologist it may be dormant. It is profitable in a qualitative science to keep definitions colloquial.

The author's viewpoint is that crater evolution is enacted over intrusion of centrospheric solar matter that geologists call magma, or "dough." Volcanology is concerned with trying to see into and measure physically this substance and its elements in action, to discover useful relations in matter, space, and time. By reason of man's limited geography he may only consider rock shell, air, and oceans and their restraining and contaminating effects. The opposite of contamination is magma. When pure it cannot be pluralized.

CONCLUSIONS

Some conclusions of this book are in Part 6; others in other parts. They cannot be condensed in a paragraph. Those suggestions of what may actuate crater development and the earth's interior are adduced from volcano experience. They are the geologist-author's best guess, after living on a famous volcano, to guide future field experiments.

Other people's hypotheses are based on mathematical cosmogony and geophysics, laboratory studies of physical chemistry, and geological mapping. These fields the present author has not invaded, but he has borrowed from them with profound admiration for their laborers.

Other subjects for future quantitative review in the record books of Hawaii include magmatic relations of earthquakes, chemistry and mineralogy of materials collected, and correlation of records with other volcanoes studied. The instruments of volcanology have also been given attention.

A conviction that comes home to one who has dwelt upon Hawaiian volcanoes is that Kilauea is probably more quoted by the protagonists of magma theories than any other volcano. In view of our persistent ignorance of Kilauea's enormous extension under the sea and the inaccessibility still of its great sister Mauna Loa, this confidence is undeserved. The evidence of things unseen is a principal characteristic of our science.

That hypomagma charged with hydrogen and other inflammable gases, and also carbon dioxide, sulphur dioxide, and nitrogen, foams by release of pressure when rock layers break seems at present a reasonable hypothesis to account for volcanic outbursts like those of Mauna Loa. Acceptance by astronomers of defect of nitrogen in the earth, and of a molten iron core, is unfortunate. No human being has ever scientifically watched Mauna Loa begin an eruption. In the first 3 hours a mighty discharge of burning froth develops. The reason for the utter quiet of magma inside just before outbreak is totally unknown. To resolve this solar performance into its chemical and thermal elements, with spectrograph, photometer, electro-magnetic apparatus, and all the resources of laboratory physics is within the range of modern science.

The absence of any perceived heat an hour before at an unbroken basalt shell, to be followed on Mauna Loa by rupture, flames, and acid gas capable of making steel drip like mercury (Jaggar, 1917d, p. 401), indicates that porous lava is an amazing insulator. Even when the furnace is working, a man behind a spatter rampart can stand close to it. Geologists who have not experienced this cannot understand the volcanologist's conviction that 2000 kilometers of earth crust is inconceivably gas tight and capable of confining heat. The local index of volcanicity anywhere by emission of heat and gas has not yet been measured, and instruments to distinguish earth radiation are among the principal quests of volcanologic science. There is certainly a difference between the Keweenawan peninsula on Lake Superior and Mauna Loa flank, and on both between July and December. How measure it day by day? This is just as important for earth science as measuring solar radiation.

The doctrine here developed of ignisepta, igneous partitions in earth mantle profound to the earth core, between permanent ocean and continent segments, or up rifts like the Hawaiian chain, considers these permanent features as distributors of intrusion. A sequel is that intrusion is the chief magmatic process of volcanism. We know geological frozen intrusives mostly in continents. It is scarcely credible that they are absent under the ocean-bottom area nearly three times as great. We know there great ignisepta like Hawaii and Tonga emitting magma, and on these lines the frozen intrusives of New Zealand and Kauai. We know the great linear deeps around the Pacific, areally parallel to lines of volcanoes, and cannot doubt but that they are over ignisepta in the mantle of the globe. Ignisepta exhibit wide and deep rift belts partly continental and partly submarine.

If intrusion is thus widespread, with potential Mauna Loas confined in the upper 20 kilometers of the globe, and ancient Mauna Loa lavas present in Edinburgh, New York, and Rio de Janeiro, and hypomagma at Mauna Loa itself transformed and emergent with gases at 1350°C., it is quite inconceivable to the volcanologist that the low temperatures of Adams or even Daly (960° and 1330°) can exist at 60 kilometers of depth, or only 1575°C. at 100 kilometers (Holmes), or a maximum of 4000°C. at 6400 kilometers (Gutenberg), the center of the fluid core! The petrologists can hardly assert that Mauna Loa is hotter than was the Hurum volcano or the caldera of central Mull. The conclusion is that thermal gradients of ignisepta are steep and that ignisepta are worldwide ancient profound features along and across the Cordillera and the Pacific deeps, in a section aross the African rifts, across the line of centers of the west Pacific arcs and of the arcs themselves, and across unmapped lines of present-day sea-bottom irruptions and lines of former eruptions recorded by geologic mapping.

Other geologic conclusions about ignisepta are that the transition zones, in North America for example, from the active Cascade volcanoes to Lake Superior, also a transition in thermal gradients, may be comagmatically graded. This gradation is both vertical and horizontal, according as tumefaction has deepened erosion. Such a cross section from Archean granite to Eocene laccoliths is the subject of countless studies of syntexis, which may some day be profitably assembled in the light of present volcanic emanation, thermal gradients, and seismicity. The gradation out to the Pacific deeps is more difficult but will be illumined when sea-bottom drilling and ocean floor physical experimentation are finally achieved for pure geonomy.

Insistence on gas as a prime mover in volcanism is fundamental and indicates that the twentieth century has departed from the nineteenth in its conception of the diminished significances of water in subterranean magma. This is the more important since ground water can violently promote contaminated eruption as shown at Kilauea in 1924. On the other hand the succession of outbursts at Kilauea other than this one, from 1909 to 1935, and all the observed effusions of Mauna Loa were clearly not steam blasts, and the vital gases were collected. The component volatiles are makers of water, by reactions nonexplosive. These are exothermic and thereby capable of assimilation. This applies to both irruptions and eruptions. The recrystallization of basalt we have seen in the glaze of vesicles and cracks and caverns, in the resorption of talus and crags, and we have melted steel pipe in a volcanic blast.

The "Strombolian" activity of the nineteenth century is the "magmatic effervescence" of the twentieth and should be kept totally distinct from the phenomena of steam blast. Steam blast produces clastic ash. Magmatic effervescence produces pumice and glass and either pure or assimilative intrusion. Pure basic intrusion may be a character of sea-floor structure. All the phenomena of crystallizing epimagma described in this book are also the phenomena of intrusion and tumefaction, when observed in craters and applied to the under-earth.

Explosive engulfment by steam blast gave the observers of 1924 at Kilauea new light, not vouchsafed to Dana or Geikie. Observation of the crater from above for 2 months added something new to the chronicles of volcanism. Engulfment of crater walls through 3 years preceded steam blast. Superficial rift outflow followed first engulfment. Extension of outflow along rift followed the higher effusion. Earthquake and inward tilting at crater accompanied preliminary engulfment. Rift-block subsidence at the shore line completed the evidence of farther extension of rift breakage. Submarine outflow became inevitable. Pure steam blast without volcanic gases at the crater followed. The crateral lava return stopped it. Bulk relations of enlarged crater proved magmatic withdrawal of larger volume than measured explosive ejectamenta. Proof of geyser ground-water explosion was complete. Nothing in the sequence resembled the carbo-sulphurous magmatic effervescence of Mauna Loa.

Some theorists have doubted the efficiency of 2 per cent by weight of volatiles. Daly, Bowen, Brun, Day and Shepherd, Gautier, Allen, all this memoir, all the work of the Geophysical Laboratory and of the students of ore deposits and modern petrology deny the validity of this doubt. Moreover, at the indicated heat emission of the deep ignisepta all elements are above their critical temperatures and are hence potentially volatiles.

Some experiments are made here in analysis by elements. Supposing atomic earth core that has discarded to a kinetic equilibrium the molecules of the mantle, its constitution not at all governed by likeness to quantities of oxides in rocks and meteorites, we need atomic analyses. Assumptions of the oxygen ratio permit no clear thinking in terms of gas-charged magma at high pressures. The Hawaiian Volcano Observatory is now considering the assumption that the elements exist (for calculation only) as monatomic gas at specified high temperature, for computing volumetric analyses. It remains to combine the quantities obtained by rock analysis and outgassing, so that a single analysis will furnish the ratio of number of atoms, as in the act of vaporizing the sample in electric arc. Working thus we may hope for comparable assembled data of astrochemistry, heliochemistry, and petrology, and for increased work with petrologic spectroscopy. Washington (1925) has touched on this problem by quoting Abbot in comparing terrestrial and solar composition.

Much geologic discussion has been directed to the age relations and hydrostatic relations of Mauna Loa and Kilauea craters. The conclusion reached in this memoir is that Mauna Loa and Kilauea are all one volcanic system, with more or less alternations of ejection of gaseous froth, from the deep Hawaiian igniseptum, to which the relative topographic heights are trivial. As to geologic age of the two domes, the physiography makes it appear that Mauna Loa in its growth was deflected to the southwest by the confining ridges of Kilauea and Hualalai. This, however, is an ancient feature of the understructures.

The present summit craters of both Mauna Loa and Kilauea are probably post-Pleistocene, are much alike, and the surface veneers from overflow and from down-break of sink craters are parallel constructions, with differences of habit. The difference appears to be that Kilauea has maintained more continuous activity of a less gassy magma, Mauna Loa a more spasmodic and pumiceous activity because of its greater resistance due to weight and bulk. The 11-year cycles show the two volcanoes keeping pace in remarkable accord.

Modern volcanology here and in Japan is measuring the rise and expansion of craters, in alternation with lowering and contraction, over magma that rises and falls. This theme has been developed by Omori and Imamura and applied in Hawaii by Wilson. The present memoir accents the correspondence between rim tilting at Kilauea and Wilson's data of horizontal angles and vertical change by leveling. By measurement of up-and-down movements of lava column, we have demonstrated the gradual upward thrust and the frequent sudden downward withdrawal, with the evidence that attributes the actual application of thrust to the stiffening of the inner lava column by loss of gas. This stiffened substance is the differentiate of the three-part lava column we call epimagma.

The elevation and lowering of the crateral region by internal tumescence, and escape of lava by intrusion or extrusion, remarkably accented in Hawaii but paralleled in Iceland, central Africa, Italy, Japan, central America, Tonga, and Samoa, and the prevalence of lowering without visible effusion, even when continued centrifugal tilting and uplift is in progress (1818–1919), make it certain that intrusion is a phenomenon under volcanoes just as important as effusion. The measurement over small areas of crateral uplift is indicative of unmeasured lesser swelling over large areas, and all this gives evidence that magmatic pressure in the earth shell is a considerable factor of elevation.

The nature of earthquakes, which are numerous and varied in volcanic crater regions, is correlated with magma but is puzzling and not at all explained. In a world of gliding, thermal unknowns, fluid core, ignisepta, totally unstudied oceanic deeps, "isostatic" adjustment and compensation considered as action, and localized circum-Pacific earthquake origins 300 to 700 kilometers deep, with great variation of determinate discontinuities and of opinion among seismologists, the word "tectonic" appears to have changed its meaning. It was once associated with the roof of the continents, Himalaya and Alps and Appalachians, supposed product of a contracting core. It has become associated with large faults—normal, lateral, or overthrust. Some of the greatest earthquakes with only minor faults are within or adjacent to ignisepta, however, and in Hawaii deeper and larger shocks sometimes occur under or near Haleakala volcano, while Mauna Loa or Kilauea are beginning or completing eruption.

There are clear-cut cases of earthquake series with epicenters where an eruption is about to break forth and the depths of origin are progressively shallower. There are many local earthquakes in Hawaii with preliminary tremor of such great amplitude that it dismantles widely distributed instruments, as though the whole island shared this as a mass movement. In general the phenomena of magmatic thrust and tumefaction are connected with intensity of earthquakes, while those of lowering magma promote frequency. Statistics show that lowest stand of magma goes with higher intensity and less frequency.

The writer knows no evidence against earthquakes being due to magmatic stress, and there are many Hawaiian earthquakes clearly occasioned by downslip on block faults, related to igniseptal tension of magma below, tumefying a larger unit, while the smaller units are faulted. The San Francisco, Valparaiso, Tokyo, and Napier earthquakes were over four of the great ignisepta of the Pacific, and the 1868 earthquake in Hawaii was at the eastern end of the Hawaiian ignisept.

There is little evidence in Hawaii that for local earthquakes the theoretical epicenter is a place of maximum motion. There is no question but that many shallow earthquakes cluster about the craters, and this checks with the gradation in time and space whereby the more intense shocks are the deeper and more general in areal effect. Earthquakes, like lava effusions, lead out to the ocean bottom, which needs to be studied by other than distant instruments.

The conclusions of this monograph point everywhere to fundamental magma with fundamental gases, and both represent a substance in broad belts extending downward vertically, this substance being a heating agent greatly confined by a nonconducting shell. By fundamental is meant substratum material from an indefinite depth that appears likely to be the matrix fluid from which syntectic continental intrusives and ore deposits have been derived.

Such plutonic intrusions are conceived to be occasioned by just as rapid development of gas inflation, vesicularity, and oxidation by acids with powerful exothermic effect as in the case of a sudden Mauna Loa outburst. There may be as much assimilation areally under oceanic islands as under epicontinental sediments. We have seen this in epimagma contaminated with talus, but if the intrusions are of the same substance as the basaltic inclusions there is no change in the resulting petrology. In the very limited areas of the continents, emergent because they are siliceous and light, gabbroid rocks are rare, except for diabase dikes and ancient volcanics, and the medial portions of the ignisepta are either batholiths or are under the adjacent oceanic deeps. Gabbro and its affiliates may be very common in the rock under the ocean. The writer is disposed to agree with Rittmann (*see* Part 8) concerning origin of sial.

The supposition that sima is world wide and the fact that basaltic magma makes up more than 95 per cent of all lavas suggest that, as pointed out by Suess, "volcanic action was at one time the dominant process over the whole earth" and "terrestrial sediments may conceal a sub-structure formed in the course of time in the same manner as the lunar surface, so as to influence all the tectonic features of the earth." The fundamental scars of a lunar earth would have to possess symmetries principally crateral and circular, or following lines of centers of circular saucers. Something of this kind is seen in the Pacific centers and arcs followed by straight and curved ignisepta of perhaps different ages.

Seasonal control of change in volcanic, seismic, and tumescence phenomena about solstice and equinox, as originally stressed by Perret and Wood, has been apparent in the facts of tabulations and diagrams here. Along with this goes the special survey that was made of the lava tide, and so much evidence has accumulated in Hawaii showing that sun and moon act upon and change crustal stresses of hypomagma that luni-solar pumping appears to be a fundamental rhythm. How it is applied is another question.

It was apparent in the tide survey that epimagma responded more evenly than pyromagma. There were marked discrepancies in the quantitative results, of different methods of reduction of data. Where so complex a fluid is involved, and the tides of the core, the mantle, the ocean, and the local crust all act upon an effervescent silicate glass, it is not surprising that the results are variable.

Wood suggested that the extra mass of the annulus of the equatorial protuberance (differentially warped where sun is farthest north and farthest south in coincidence with tidal maxima of the moon) makes the rock tide especially effective on an east-west tropical ignisept like the long Hawaiian ridge. This would account for the importance of pressure changes at solstice and equinox, when solar pulls change direction.

The computed effect is very small, but it may be much greater if the mosaic of interseptal mantle blocks has mobility over the centrosphere. Such slight mobility on magma partitions might be just enough to make different volcano chains behave differently according to their direction and length.

One reason for citing in Part 5 a list of references to former routine publications of the Hawaiian observatory is to avoid reiteration of some former conclusions. Our laboratory has tried many kinds of measurements that give negative results. The objects of science at an active volcano are divided among geochemistry, physics, dynamical geology, structural geology, and the practical applications of engineering that concern human safety.

Physics and chemistry of magma lead us directly to astrophysics. Meteorology has been the subject of measurements ever since the Observatory was founded but has usually yielded negative result when correlation was sought between such things as magma and rainfall or barometric pressure. Island triangulation conducted by government surveys has encountered surprising failings of closure on the flank of Mauna Loa. Leveling has met difficulties in trying to find the true sea-level datum. Crater bench marks have been repeatedly destroyed.

It becomes necessary to select among physical measurements, and geographically all our work points to establishing observation at the top of Mauna Loa and at the bottom of the sea.

After 30 years of dwelling upon an active volcano I would suggest caution in applying the pure physics of an isotropic solid to a heterogeneous body like the earth, until such time as its vast surfaces are harnessed with local measuring apparatus and we know the mineral, thermal, seismic, and electromagnetic properties of the rock under ocean muds.

This is a far-reaching philosophy. The "uniformity" of Lyell applied to time was full of ignorance of space. The San Andreas fault became "typical" in textbooks and is now gospel in California seismology, with little reference to the ocean depths to the west or the magma under Napa and Geyserville. Volcanic earthquakes were trivial and shallow because volcanoes were little steam engines; ignisepta were not noticed, and Stübel actually combatted linearity, on the most magnificent linear magmatic belt in the world. With petrology studying igneous rock, no one attempted to measure secular movement at Napa and Geyserville, though eventually the gases and waters were admirably studied.

The doctrine of uniformity called for prolonged and localized observation of all processes on and in the earth. The greater number of localities are the intrusion chambers in action inside, and the faults, graben, effusions, shakings, thermal conditions, sedimentings, possible laccolithic domings, and ledges of that three quarters of the earth which is difficult of access—but not difficult to the cable companies or the oil companies that tap under-sea petroleum. Increasingly precise physics and engineering reach deep inside the earth and sound the sea by echoes, and drilling can be carried thousands of feet with machine swiveled on a barge in water. Water surface has the advantage that it is the top of a ready-made oil derrick. The earth inside and out is not nearly so remote as the stars.

Are intrusion chambers in action inside? The Pelée spine, Bogoslof and Tarumai domes, and lava hills of Santorin are intrusions that extruded and are dated. The petrologist's specimen of a laccolith in the Henry Mountains represents an irruption of say October 15, 10^n years B.C. It was not a vague "Tertiary" age. It was an inrush, "irruption". Daly's maps of the linear batholiths of Cordillera and Appalachians, the former curved, the latter straight (like Sunda arc and Philippines), stand for deeper events of larger timing but made of individual ingushings dated. The Yellowstone, New Zealand, the Cascade Mountains, Japan, Arkansas hot springs, and Italy are over shallow intrusion now in action, dated. On top is the cumulo dome, next below are the laccoliths, farther down the batholiths, still farther down the great ignisepts, the widening relic of a pristine rupture that resulted from a lunar earth assembling its oceans.

Volcanism made dated events of constructed maria by millenia, ring saucers by centuries, rim craters by years, and small pits by days, on a crusting sphere. Intrusions inside the earth today, yesterday, tomorrow are attested by millions of geological radio calls, quakes, tremors, microseisms, fault motions, landslips, submarine happenings, eruptions where man is not. The crust is a profound solid barrier, static, rigid, huge, opposing transmission, and man does not cover 0.1 per cent of the receiving ground for the messages.

The crater of Etna is a place of millions of earthquakes; we record only Messina because it is big and we are 5000 kilometers away. From 300, 400, or 700 kilometers down we record the *greater* deep earthquakes; we do not get those 2900 kilometers down, but that does not prove they are not there. Seismometry is a record of limital sensitivities of instruments. Mauna Loa eruptions only 22 miles from a seismograph may go almost unheralded and send up gigantic gas fountains for days totally unperceived seismically. Inrush making dike, sill, or boss by magma overcoming restraint stands for millions of dated events that we are not even trying to locate. Intrusive wedging, largely marine, the magmatic pressure, is neglected.

And so we read (Washington, 1925, p. 351) "a solid central core of nickel-iron surrounded by a series of solid progressively varying silicate shells now meets with the general acceptance of geophysicists." This astonishing statement is taught to thousands of young geologists, is credited to Oldham, Wiechert, Gutenberg, Suess, Daly, Clarke, Adams, Williamson, and Washington, and "as stated above is now the practically unanimous belief."

The author dissents with all the vehemence he can command. He dissents against any unanimity or any "belief", but as a volcanologist he is representative of some of the above-named men of science who are quoted in this book. All realize that earth science is in flux and is eclectic. Volcanology leads experiment to a kinetic earth with a fluid core, intensely intrusive along ancient belts, very slightly extrusive, with only the mantle rigid, and that mantle very thick. Volcanoes are the contaminated tiny exuvia of volcanism.

These impressions, for they are nothing more, agree in part with seismology and have no quarrel with the petrology of continental diastrophism. But it is the petrology of syntexis. Pure magma as solar matter is essential to the scale of things volcanic, and gradations of scale from the colossal Hawaiian ridge, 35,000 feet above its neighboring lowland, to the still greater solstitial ecliptic belt of mediterranean oceans and thence to the Pacific circle of deep earthquakes keep volcanology at field work in true geonomy, with insistence that we shall experiment with the physics and chemistry of craters.

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PLATES

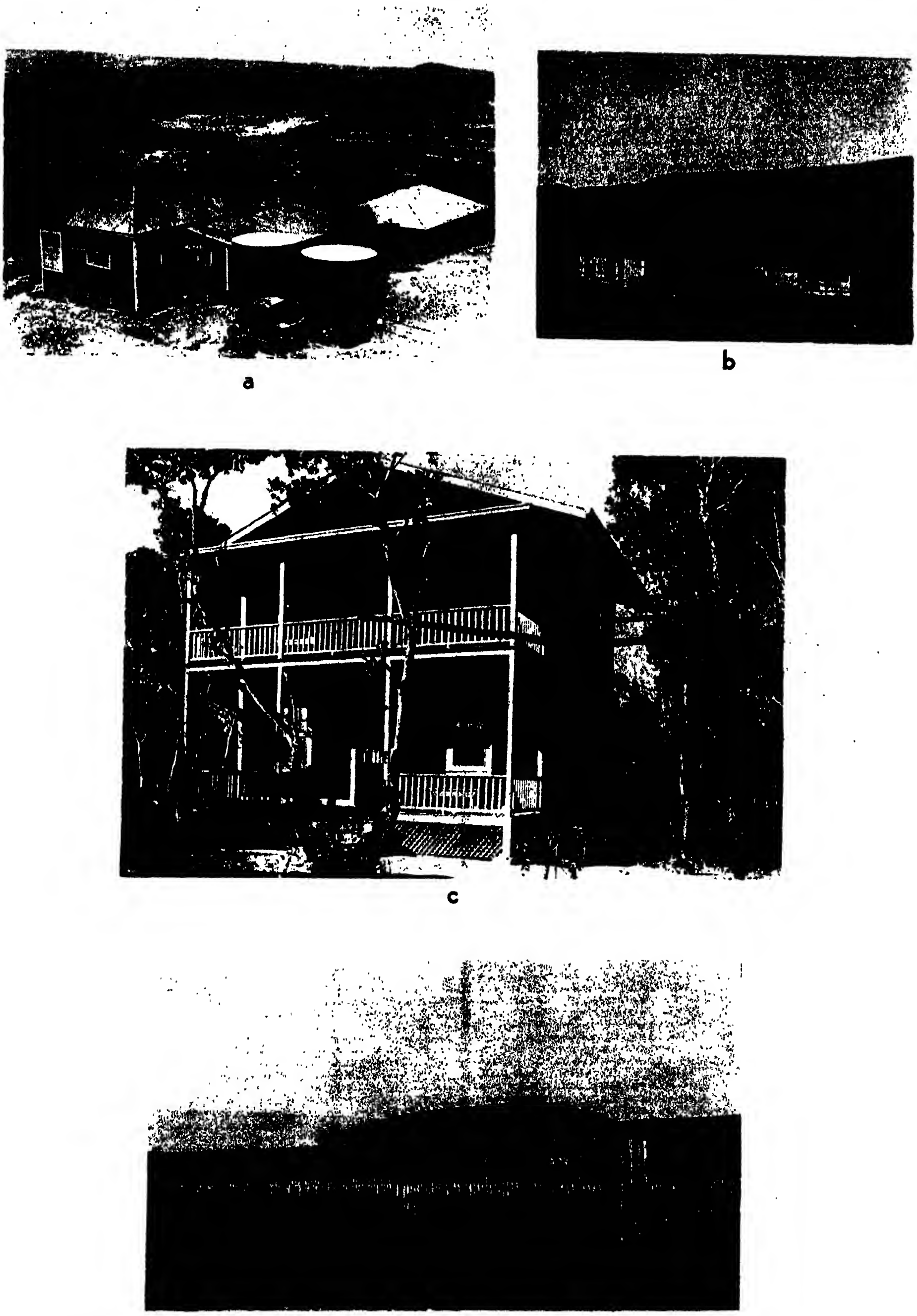
PLATE 1.—HAWAIIAN VOLCANO OBSERVATORY BUILDINGS

a. Hawaiian Volcano Observatory from top of drill tower with tanks, Archives building, Volcano House, Sulphur Bank, and Mauna Kea, looking west, 1923.

b. Puu Ulaula resthouse Mauna Loa northeast 10,000 feet, 1916.

c. University of Hawaii Building at Kilauea, 1930.

d. Instrument hut at Halemaumau, north side (looking northwest), January 14, 1913.



HAWAIIAN VOLCANO OBSERVATORY BUILDINGS

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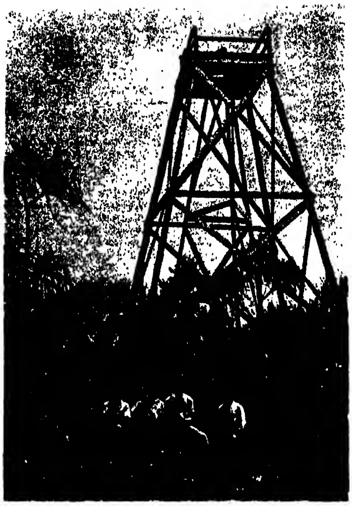

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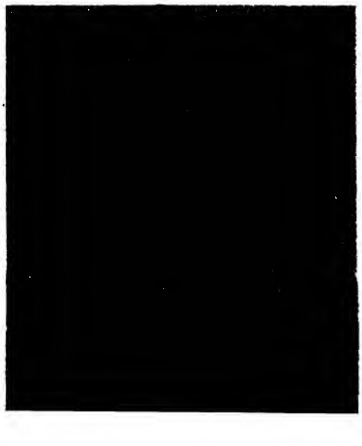


PLATE 2.—OBSERVATORY FIELD METHODS

a. Kilauea Crater, Mauna Loa, and Volcano House from Observatory grounds, looking west, 1910.

b. Rotary shot drill at work, boring gas-temperature holes at Sulphur Bank, Kilauea, February 1923.

c. Triangulation tower 1 mile southwest of Opihikao, Puna, 1933.

d. Rotary drill tower Observatory grounds, 1922.

e. Churn drill of Hobart Engineering Co., east floor of Kilauea Crater, 1922.

PLATE 3.—OBSERVATORY FIELD METHODS

a. Camp Mauna Loa summit, near Wilkes campground, east side Mokuaweoweo, 1913.

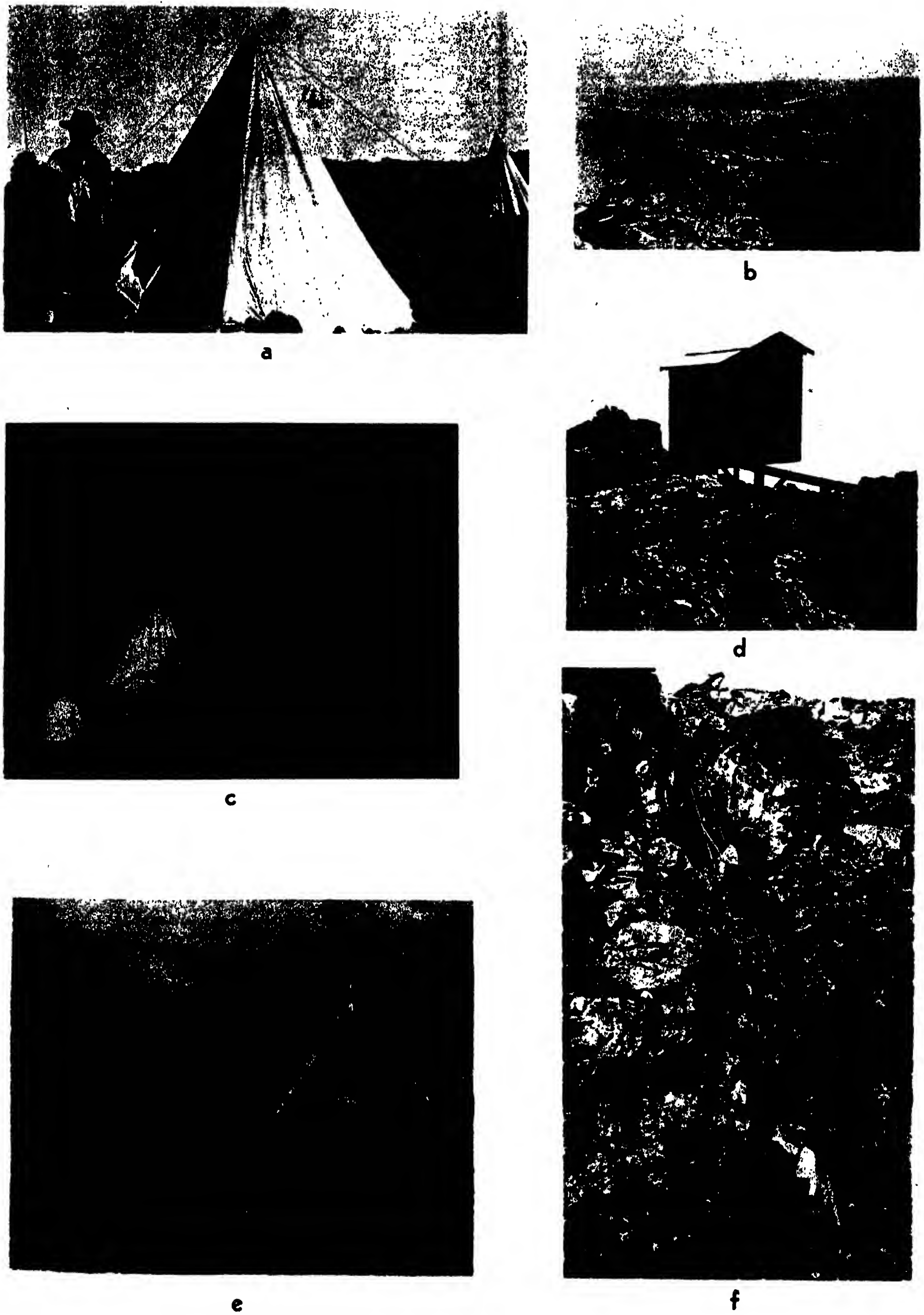
b. Hut, corrals, and instrument shelter, north edge Halemaumau, 1913.

c. Tepee tents at night, camp at Waiohinu, and two fire columns of Mauna Loa in background, 1916.

d. Instrument shelter, north edge Halemaumau, 1913.

e. East trig station Halemaumau, and 1894 shelf, looking northwest, 1916.

f. Rope ladders in use, northwest wall Halemaumau, January 1917.



OBSERVATORY FIELD METHODS

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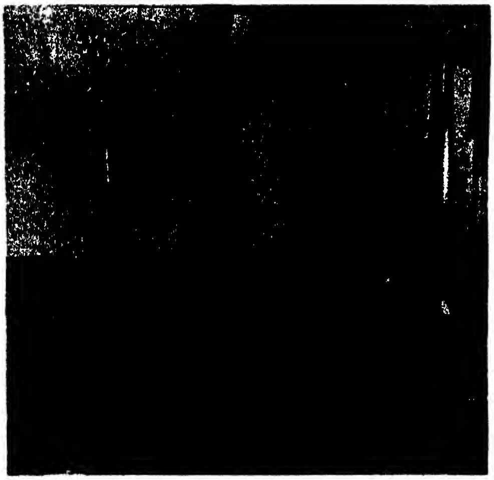

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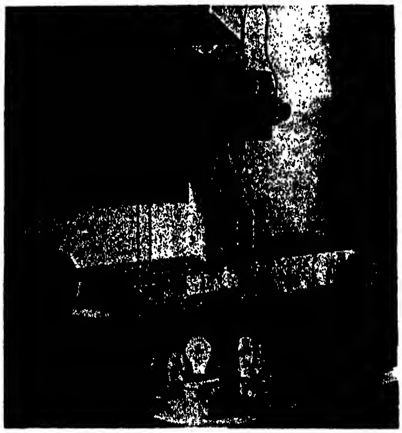

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PLATE 4.—OBSERVATORY SEISMOMETRIC EQUIPMENT

a. Seismograph cellar with Omori "ordinary" three-component strong-motion instrument, and Omori east-west heavy tromometer, 1912.

b. Seismograph cellar with pair Bosch-Omori two-component instruments added, 100 kilograms each, separate drums, 1916.

c. Vertical-component seismograph, with temperature compensation by springs, built at Observatory, 1925.

d. Bosch-Omori two-component seismograph recording on single drum, 1920.

e. Radio station for common time signal on all instruments at Kilauea and Mauna Loa, Hawaii National Park, 1939.

f. Mauna Loa two-component seismograph built at station operating at end of Mauna Loa road, elevation 7000 feet, 1939.

Plate 5.—ASH AND LAVA PRODUCTS

a. Pool of dried ash, originally mud, with footprints after explosive eruption, southeast of Halemaumau, June 1924.

b. Pele's hair and avalanche dust after great subsidence in Halemaumau, at leeward edge of Pit June 6, 1916.

c. Lava toe of pahoehoe of 1894 on central Kilauea floor, shark-skin lava, toe detached and fallen off while incandescent with pasty "umbilical cord" connecting it with its matrix. Scale shown by foot rule below. September 29, 1916.

d. Same kind of detached toe with scar of its "navel", smooth lava of 1894, central Kilauea floor, showing bulbous surface from which it departed. Photographed September 29, 1916.

e. Pisolitic ash of 1790 from Kau Desert region, showing the fossil rain drops embedded in ash, indicative of torrential rain, necessarily contemporaneous with eruption when the air was full of dust. Photographed by Perret, 1911. Natural scale.

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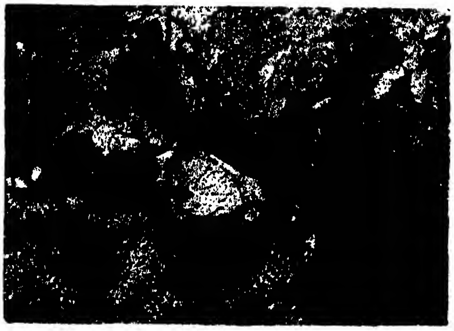

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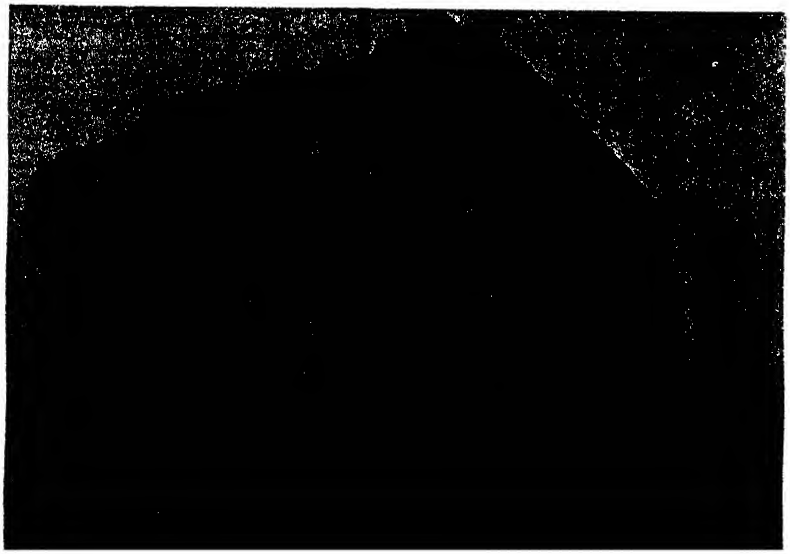

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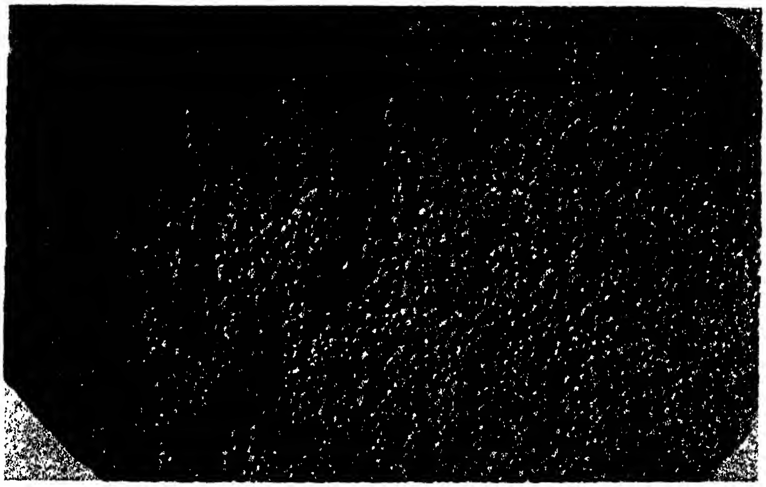

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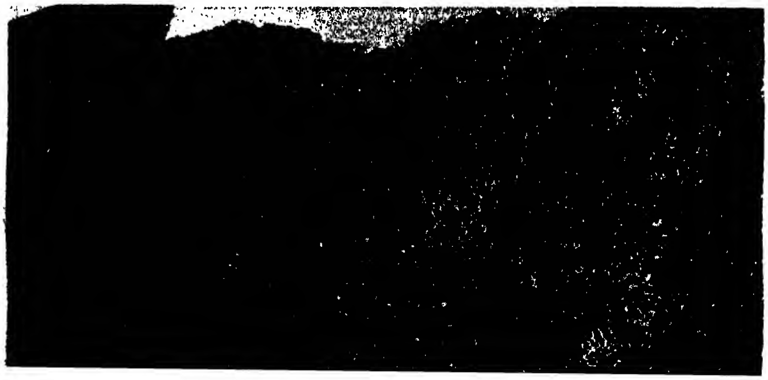


PLATE 6.—LAVA TEXTURE

a. Coarse vesiculation of Kilauea lava characteristic of sprouting aa flow.

b. Uniform vesiculation of Hawaiian lava characteristic of upper layers of pahoehoe flow.

c. Filamentous pumice of Kilauea, under ash soil near Kilauea Iki, the "thread-lace scoria" of Dana, which differs from most of the later basaltic pumices of Mauna Loa and Kilauea in that the vesicle walls are threads rather than membranes. Photos by Perret, 1911. Natural scale.

PLATE 7.—LAVA TUNNEL STRUCTURES

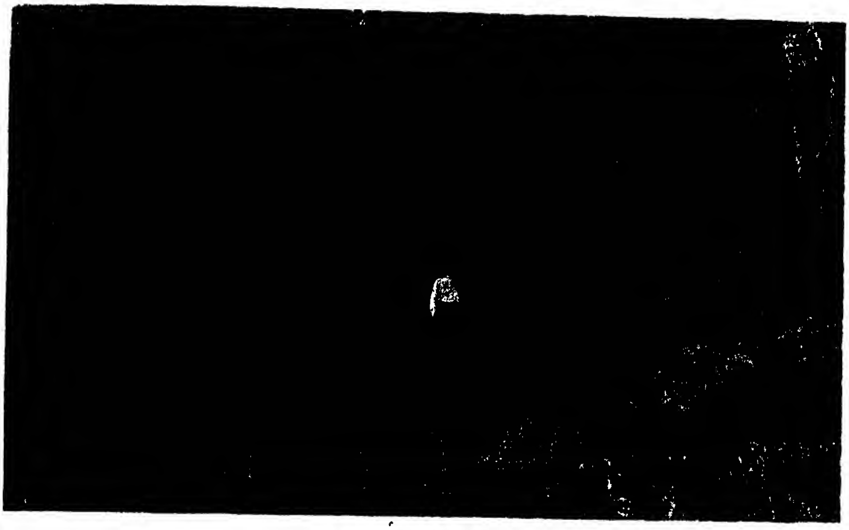
a. Lava tunnel in north wall of Halemaumau showing sewerlike character of an overflow channel crusted in at top and sides. This was preserved until 1917 when liquid lava in Halemaumau rose to this level and poured for many hours filling the tunnel, and so leaving a "snake" form of intrusive of circular cross section transversely, and elongated cylinder longitudinally. Such cross sections are seen in west wall of Kilauea Crater. Lower walls of Hawaiian craters show no tunnels because they have all been filled up in this manner, except those so close to the surface that recurrent overflow has not reached them. This disposes of Hobb's contention that the deep structure of Hawaii is honeycombed with caverns. Photo Perret, 1911.

b. Worm stalactites, gas melted, from roof-glazed lava cavern of 1919 northwest part of Kilauea floor about 1930. Stalactites formed when walls were incandescent, and reheated by gas reactions of gas-filled chamber. *See* Part 2, June 20, 1919.

c. Interior of the lava flow-channel known as Thurston's Tube east of Kilauea, showing roof under forest above; filamentous roots of trees and horizontal marks at side made by lowering stream, as eruption declined. About 1920.

d. Roof opening of lava tube of 1894, central floor of Kilauea Crater looking northeast, showing outer aspect of a collapsed lava tube similar to c. This tube is hot and known as "Pele's bathroom". About 1920.

e. "Walking-stick" and "grape-vine" stalactites and stalagmites, from molten glaze in cavern northwest part of Kilauea floor, flow of 1919, photographed about 1930.



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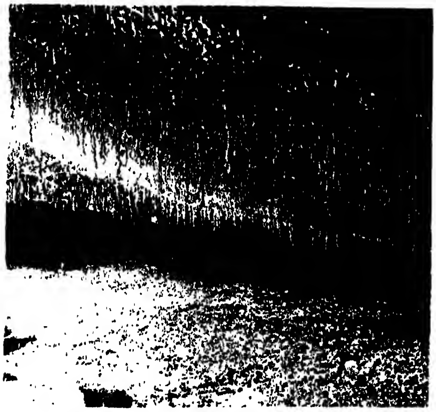

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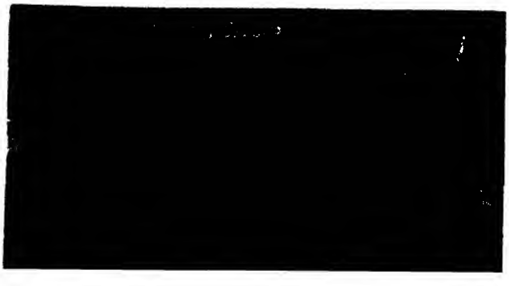

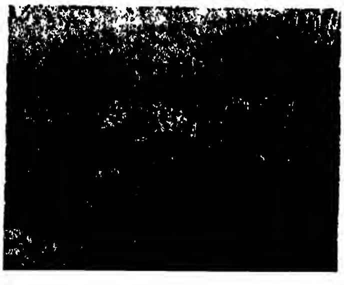


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PLATE 8.—FEATURES OF KILAUEA CRATER

a. Kilauea floor and distant Halemaumau, seen from Observatory looking southwest, showing vapor effect of heavy rains for weeks in August 1914. *Compare* c.

b. West wall of Kilauea Crater showing unconformity of lava flows and tunnel intrusions, over old ash-covered mountain top; probably Pahala formation (Stearns and Clark, 1930). May 27, 1917, looking northwest. These uncomformities were buried by the overflows of Kilauea floor in 1919–1921.

c. Halemaumau from Observatory in dry weather, at a time when the pit made fume and vapor. October 1, 1912.

d. Perret's cone, a very hot spiracle over a deep vent in north floor of Kilauea Crater, surrounded by 1894 lava, July 19, 1914.

e. West wall of Kilauea Crater south of Uwekahuna summit, showing unconformity of lava, on what is probably Pahala ash, July 29, 1913. Now obliterated by 1921 flows.

f. The Sulphur Bank solfatara, north shelf of Kilauea Crater, representing solfataric activity of an old marginal wall crack of the crater for a higher level of earlier days.

PLATE 9.—HALEMAUMAU AND PIT CONSTRUCTION

a. Northwest wall of Halemaumau showing circular effect of engulfment within concentric accumulation. West niche of 1894 in background, and the A-frame of Shepherd-Perret temperature experiments of 1911.

b. Curtis model of Halemaumau in spring of 1913 looking north (Harvard University). Shows concentric outer cracks of Postal Rift representing Pit rim of the 1891 engulfment, later filled to overflow in 1894, then emptied for an inner pit in July of that year. Shows road terminus, Volcano House trail, the 1894 northeast shelf and west niche, huts on north rim, and the white spot with temperature 320°C. where tourists browned postal cards (Postal Crack).

c. General view of same showing Kilauea Crater, the subsided shelves of its northeast and west rim similar to the craters on the moon, intrusions in west wall, light-colored ash deposit at base of latter, and distant Mauna Kea. Perret's cone is the light object in north floor, and the lava torrents at the left were the last gushings of 1894. Most of the surface shown is 1894 lava excepting the small light-colored V at the right hand edge, which is earlier. Note that Halemaumau is in a cone 200 feet above the base of the distant wall. Modeled spring of 1913.

d. The moon mechanism of circular crater building, illustrated also in Plate 10. Halemaumau about 1892–1893 looking west showing in background wall of 1891, and behind that the wall of Kilauea Crater. Circular lava lake with border rampart created by up-flux within contemporaneous incandescent accumulation, and alternate down-flux causing concentric breakage. Perfect circularity is rarely achieved, and the lake shown was oval. Frequently such lakes tend to pentagonal or hexagonal outline. The subterranean control in Kilauea is a rift-fissure trending northeast.

e. Two pits in Kau Desert near Puu Koae, showing the effect of drainage of such a lake as d. These are more than 250 feet deep, and connected by a horizontal tunnel at that depth, representing probably a source crack.

a

b

c

d

e

a

b

c

HALEMAUMAU 1909–1910 COMPARED WITH VESUVIUS

PLATE 10.—HALEMAUMAU 1909–1910 COMPARED WITH VESUVIUS

a. Halemaumau, Uwekahuna cliff, and Mauna Loa looking west January 13, 1910. Shows subcircular lava lake within 1894 wall, northeast shelf on the right, innumerable traveling and bubble fountains, spatter ramparts and floor outflows within Halemaumau pit on the left. Depression about 100 feet.

b. Similar condition of December 23, 1909, looking west with 135 feet of depression. This was after a temporary lowering as shown by breakage on the left and scars on the walls. Lake is wholly within its ramparts, built high by violent fountaining action, and marginal steaming is greater than in a. Some of the lake margin elevation may be epimagmatic uplift.

c. Vesuvius after 1920 for comparison with Halemaumau. The more viscous magma builds a steeper inner cone, a similar but rough floor, and more concentrated gas action at a smaller fountaining inner pool. The cone-in-cone character generated by concentric construction, and destruction, in cyclical alternation is quite the same, but the outward dip is steeper, and marginal intrusion more conspicuous.

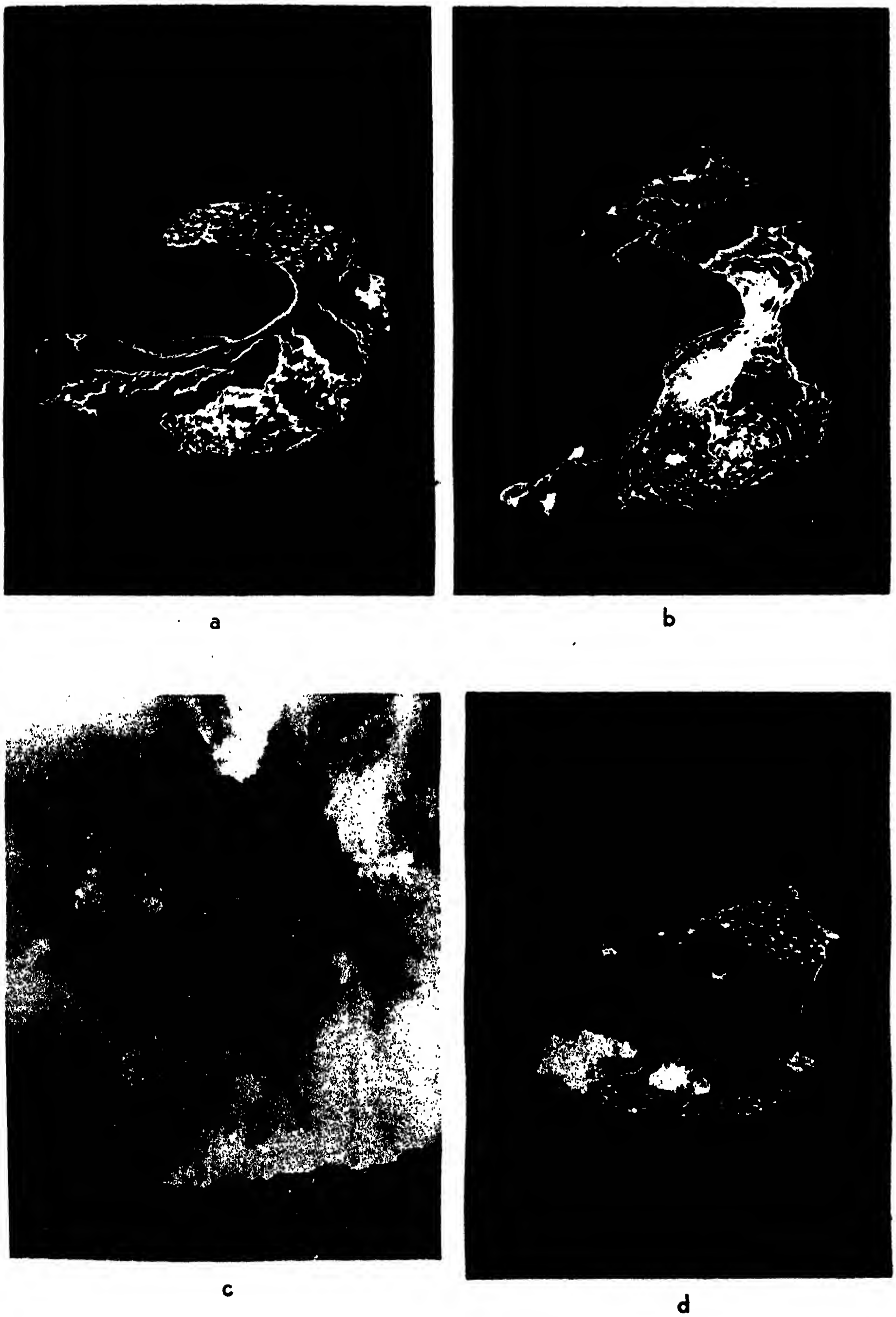
PLATE 11.—LAVA LAKE 1913

a. The lava lake at night looking west January 19, 1913 depression 378 feet, bubble fountains in source pool partially crusted over at the west, streaming and tearing crusts with larger fountains at the east.

b. The lava lake at night (1 a.m.) looking west, February 28, 1913, depression 472 feet, showing west source pool higher than east sink hole, cascade between and helical whirlpool at the site of Old Faithful fountain.

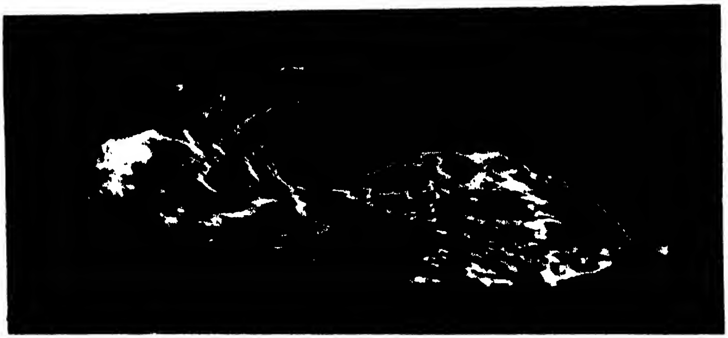
c. The lava lake by day looking west, March 10, 1913, with south peninsula converted into an island, marginal shelf left by engulfment, and heavy marginal fuming. Depression 446 feet.

d. The lava lake at night looking west, March 10, 1913, showing bubble fountains at source pool, streaming east on both sides of island. Vortical action tends to streamline island to heart shape, bright-line pattern on custs, and large fountains at meeting point of currents. Depression 440 feet.



LAVA LAKE 1913

a



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c

Plate 12.—LAVA LAKE 1913–1914

a. Lava lake by day looking south, January 25, 1913, showing bubble fountaining of source pool on the right, streaming to the left, and inner shelf built by a rising spell. Depression 376.5 feet.

b. Same scene by night, January 26, 1913, showing bright-line pattern and Old Faithful fountain on the left. Depression 374.5 feet.

c. November 9, 1914, reappearance of lava lake in fuming floor looking west, depression 469 feet. Again the streaming is from wall-crack sources at the west and the large fountaining in a sink hole at the east. There are two source cones.

d. Lava lake, December 17, 1914, looking south after development of a southwest source arm where the smoke holes are shown in c. Streaming is from the two western coves, and again Old Faithful is seen in a line of fountains in the large eastern lake. Depression 409 feet.

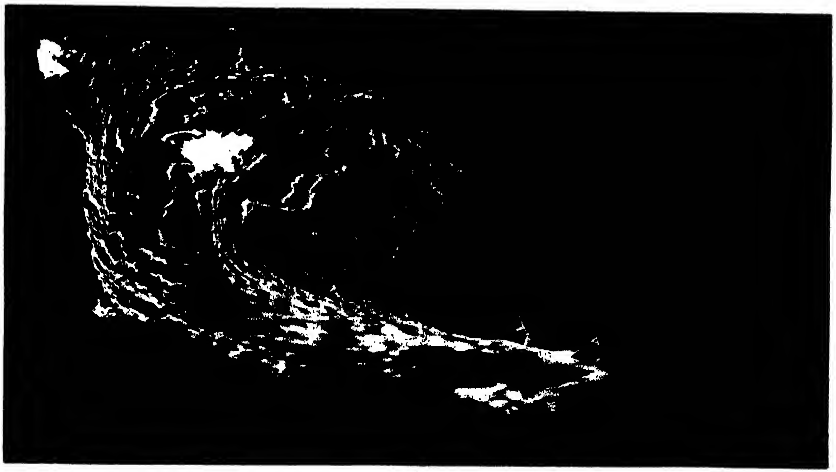
Plate 13.—LAVA SUBSIDENCE 1915

a. January 31, 1915, avalanches from northwest wall of Halemaumau during a sinking spell, along with much fume. Depression 436 feet.

b. Whirlpool again developed by differential sinking, with a cascade from source pool to larger eastern lake. February 2, 1915, exposure of photograph 1 second looking south.

c. Same with exposure of photograph 23 seconds showing speed of torrent, distribution of luminosity, and loci of central and border fountains at the east. Depression 440 feet.

a



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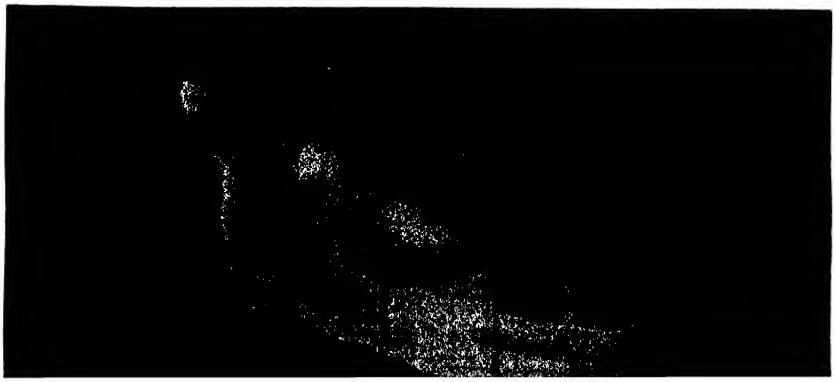
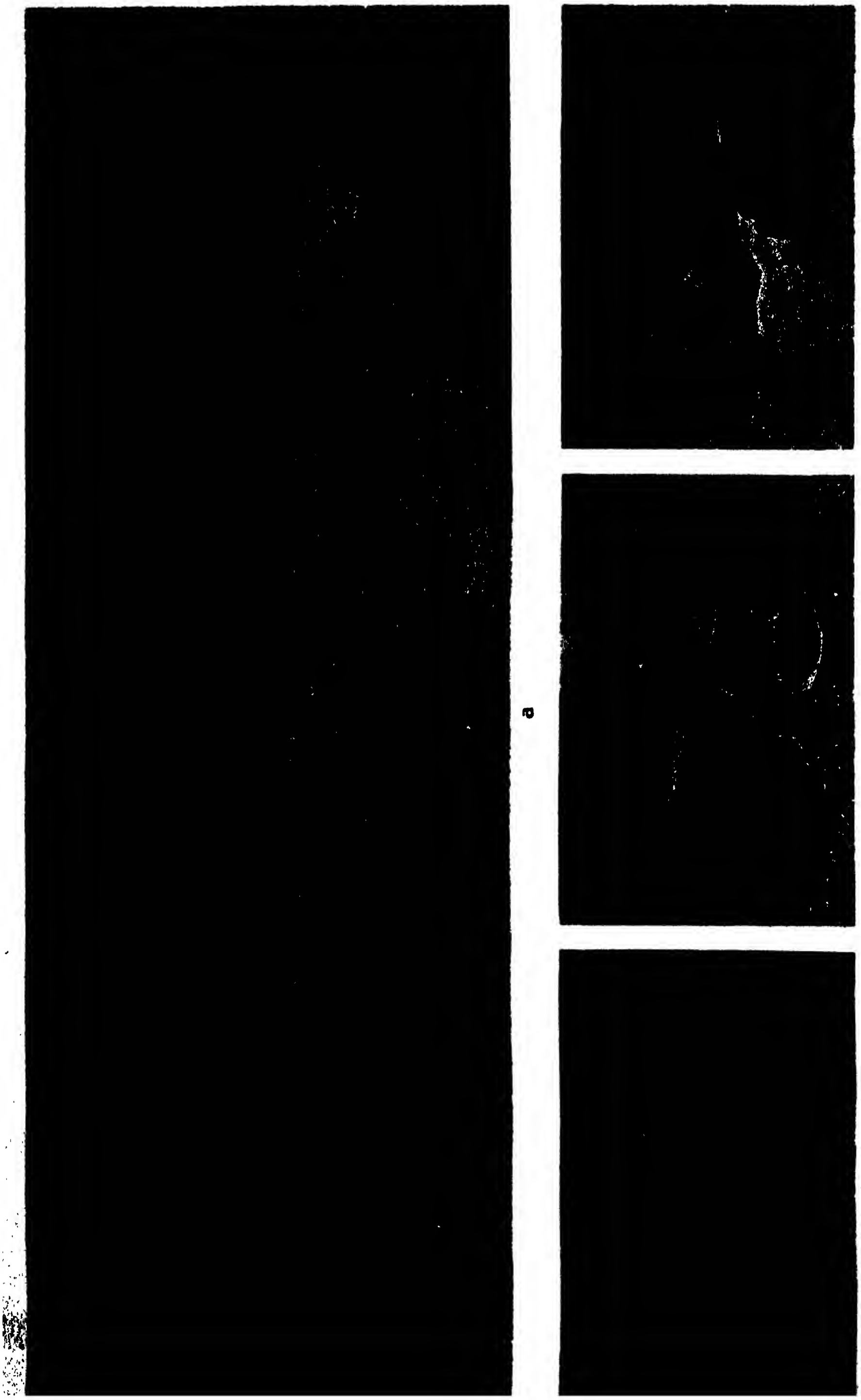




LAVA CRAG DEVELOPMENT 1916

PLATE 14.—LAVA CRAG DEVELOPMENT

a. Lava lake looking NNW April 11, 1916, with form like an S and the first development of epimagmatic crags tilted up from the floor by internal tumescence and rising. Depression 342 feet. Local source of radial flows in foreground. Torrential streaming as usual from west to east through narrow channel between the two crags. Central fountain and border grottoes at the east.

b. Lava lake May 14, 1916, looking SE, depression 322 feet. The upright block of epimagma under the crag had executed a rotary movement around a vertical axis against the bank, a very unusual happening, but not in any way due to flotation. The lake now appears circular. Rapid rising was in progress, to be followed by collapse in June.

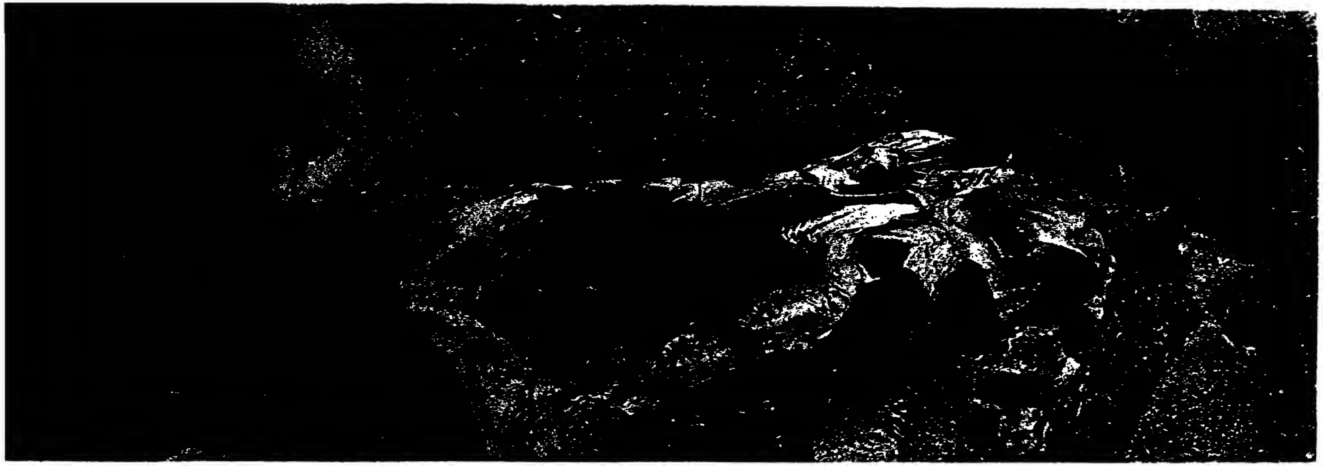
c. The collapse left a funnel of large taluses immediately filled by a saucer of lava with lake of oval form shown in Plate 15 a. The photograph in Plate 14 c is the lava lake looking NE, showing the upward swelling of the margin of the saucer, and of the epimagma of the lake bottom to make the round island in the foreground. Further uplift of this made the great west crag. August 16, 1916, depression 390 feet.

d. A lava brook or torrent of molten liquid cascading from small northwest pond into north arm of lake, looking down and toward the southwest from north rim of Halemaumau September 13, 1916. Depression 326 feet. The slope of fragments in the background is part of the great west crag mass.

Plate 15.—LAVA RECOVERY 1916

a. Lava lake from the southwest, June 24, 1916, showing the three great talus cones of the collapse, and the immediate fill with liquid lava to an active streaming oval pool surrounded by a shore of its own consolidation and underlain by a saucer of semiconsolidation destined to develop in 5 months into what is shown in b. These incredible changes by tumefaction, with differentiation of lake magma and bench magma, were to be characteristic of Halemaumau fluctuation for the next 6 years. The smoking bench in the left background became both the source pond and maximum crag development, and the spattered bench at the right became the eastern sink-hole region of border grottoes. Depression 577 feet.

b. This panorama from the southeast November 13, 1916, depression 190 feet, shows the rising and swollen pudding of epimagma with its contained source wells at the left and sink-holes at the right and a streaming from left to right that may be thought of as a lava flow in delta shape within the confinement of a lava pit. There is still the trace of the top of the western talus cone on the left. This landscape introduces the experimental period of the Observatory in 1917 when repeated descents were made to the floor shown in the background at the right, and by rope ladder to the great western crag mass in the center. The southeast crag island at the right became joined by uparching of the lake bottom with the long peninsula at the left.



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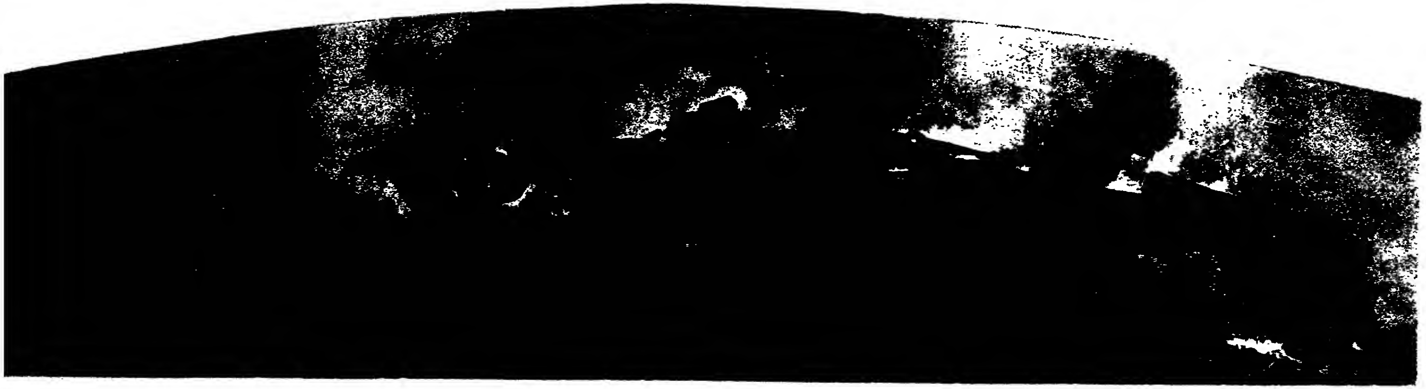

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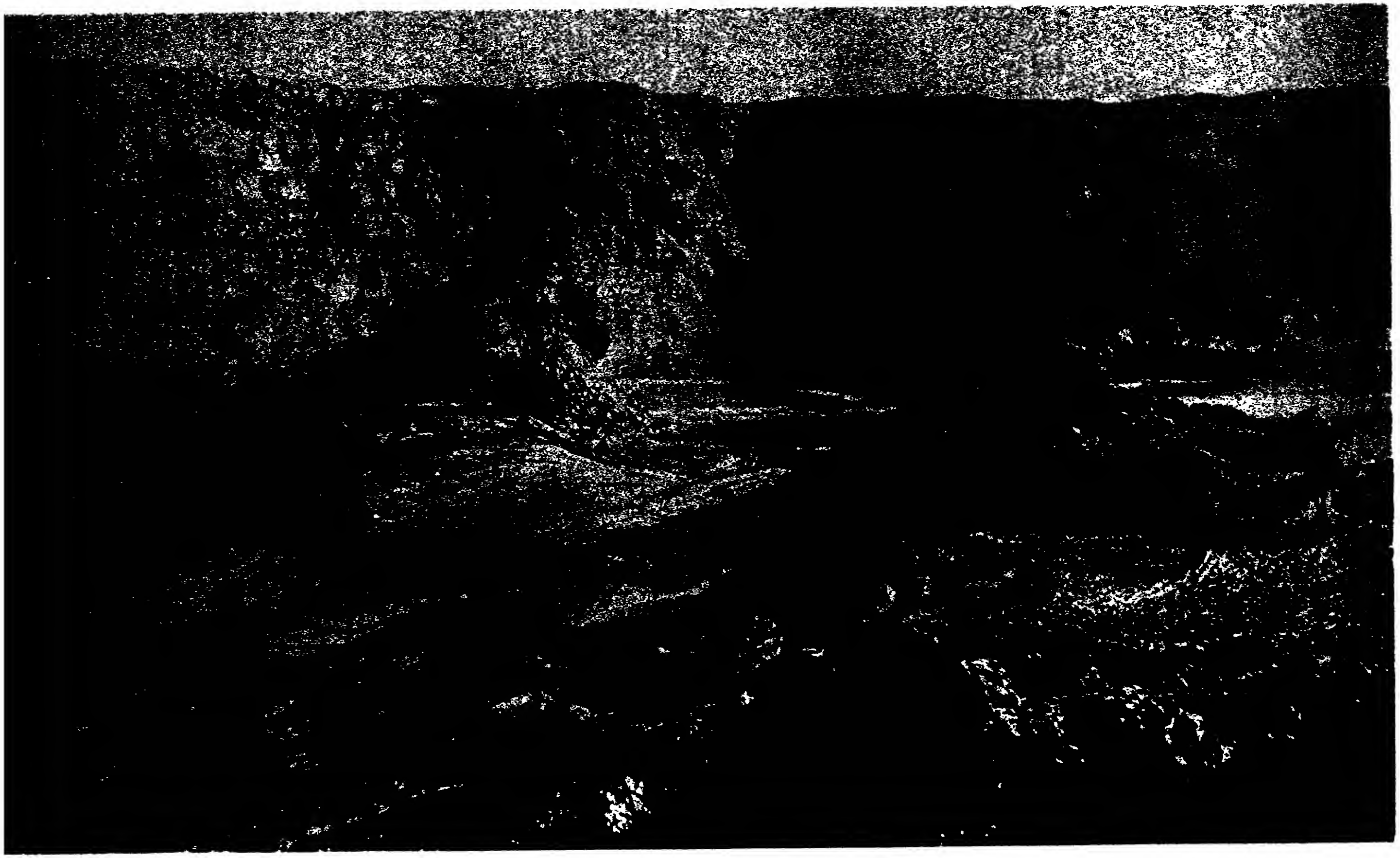


PIT LANDSCAPE 1917

PLATE 16.—PIT LANDSCAPE

Southeast crag island and east floor of Halemaumau photographed from within the pit looking south January 5, 1917, depression 105 feet. We are here standing on the bench magma of the lava column amid hot fume, with the streaming lake between us and the crag, and a fresh overflow in sunlight on the left.

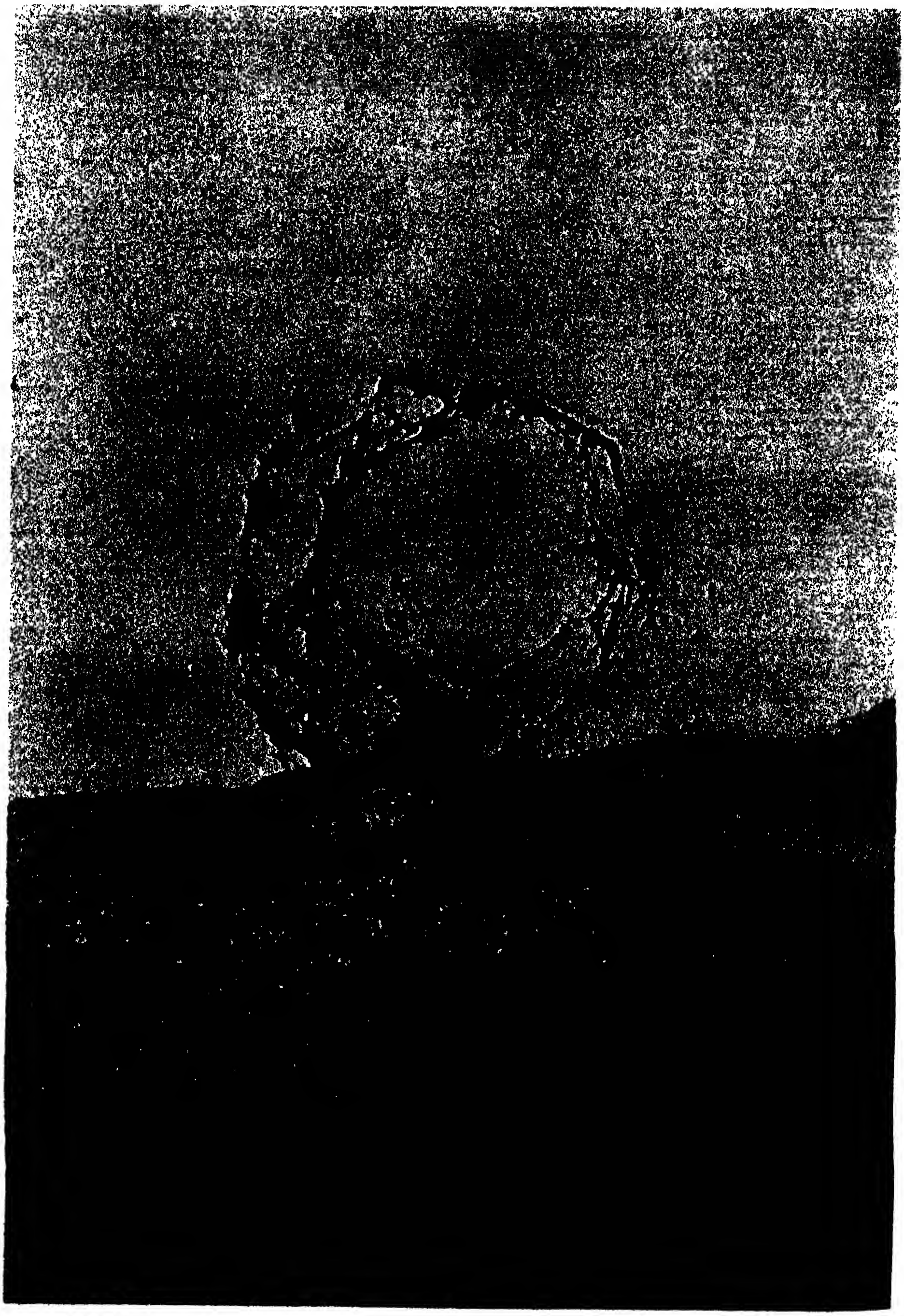
PLATE 17.—DOUBLE-CONE SPIRACLE

a. North floor of Halemaumau with huge ramparts of fountaining grottoes of north arm of the lake on the left, and a remarkable double-cone arch shown in the distance. January 3, 1917, depression 105 feet.

b. The double-cone arch built up by lava spurting through cracks in the floor just outside the lake rampart. This is over fountaining cupolas below, building spiracles above on a covered tunnel extension of the lake.

a

b



FOUNTAIN ACTION 1917

PLATE 18.—FOUNTAIN ACTION

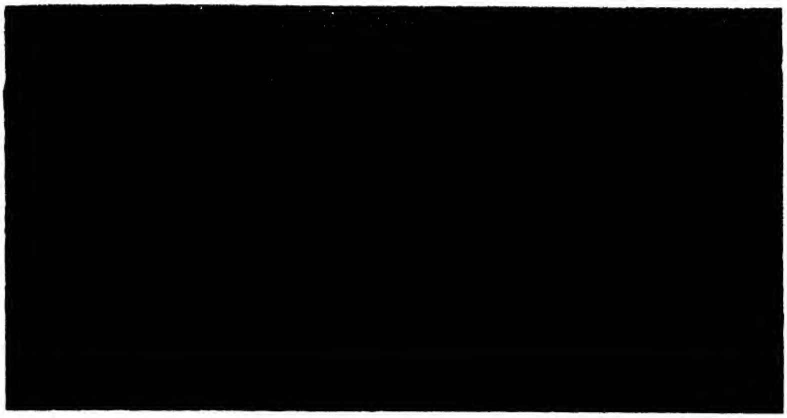
Border grotto fountain flinging Pele's tears and spinning Pele's hair 25 feet from the camera, southeast cove of lava lake May 23, 1917, depression 70 feet. The fling of the surge in a circle is occasional by surflike vortical forces where the rush of gas-impelled foam shoots up from the rupture of heavy crust over a sink-hole where there is probably a cascade into a well.

PLATE 19.—STAGES OF INNER OVERFLOW

a. Halemaumau looking northwest May 29, 1917, fresh overflow on floor from main lake. Depression 36 feet.

b. Same, 19 minutes later showing flow pooling and filling northeast wall valley.

c. Same, 12 minutes still later showing large pool under 1894 bench and crags in the pit.



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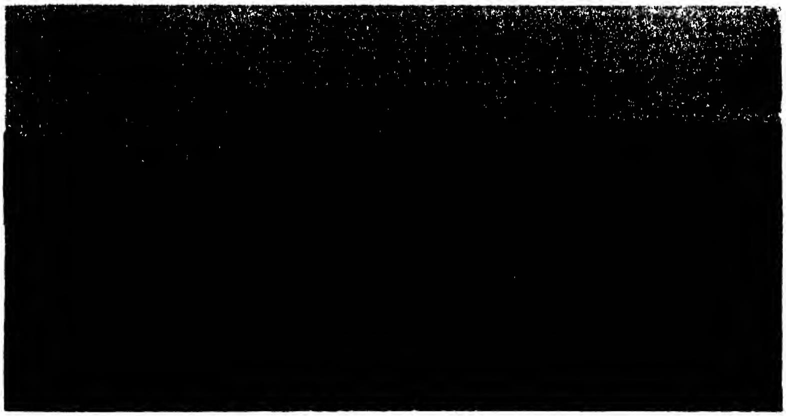

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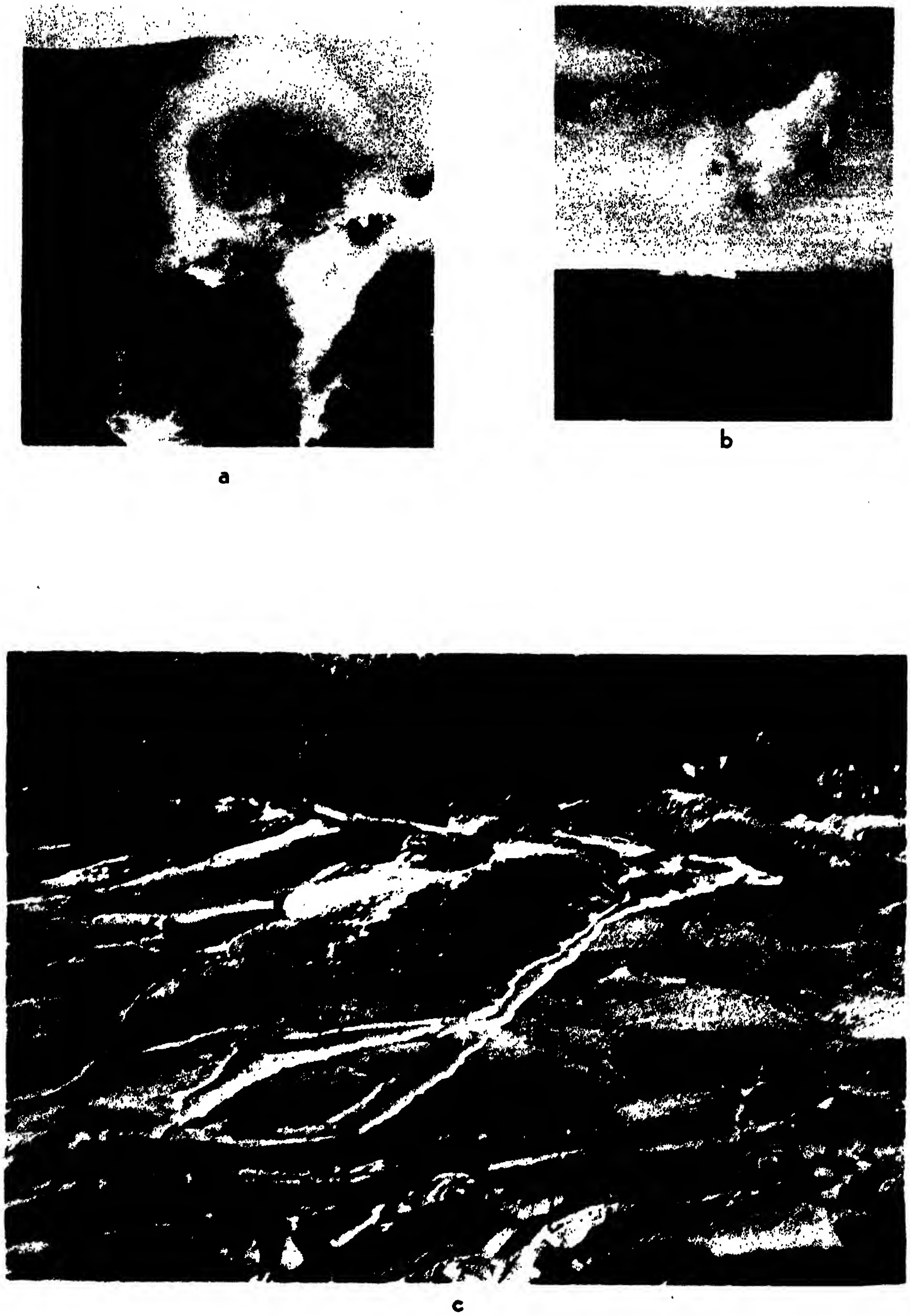


VAPOR HABIT AND LAVA MECHANISM 1916-1920

PLATE 20.—VAPOR HABIT AND LAVA MECHANISM

a. The eddy under northeast wall of Halemaumau outlined by fume showing how the trade wind from northeast makes inward suction on windward side. March 11, 1920. Depression 217 feet.

b. Halemaumau from Observatory December 27, 1916, showing steam cracks around pit margin, thin fume above pit, and condensation of rain cumulus still higher.

c. Northern wall valley of Halemaumau floor filled with live lava showing fan-shaped block of crust cracking and foundering with liquid lava welling up and bubbling around its edges. This is the "cracking and foundering process" whereby the greater weight of the crust over the gas-charged liquid lava below is demonstrated, January 4, 1917. Depression 105 feet.

PLATE 21.—LAVA SOUNDING EXPERIMENT

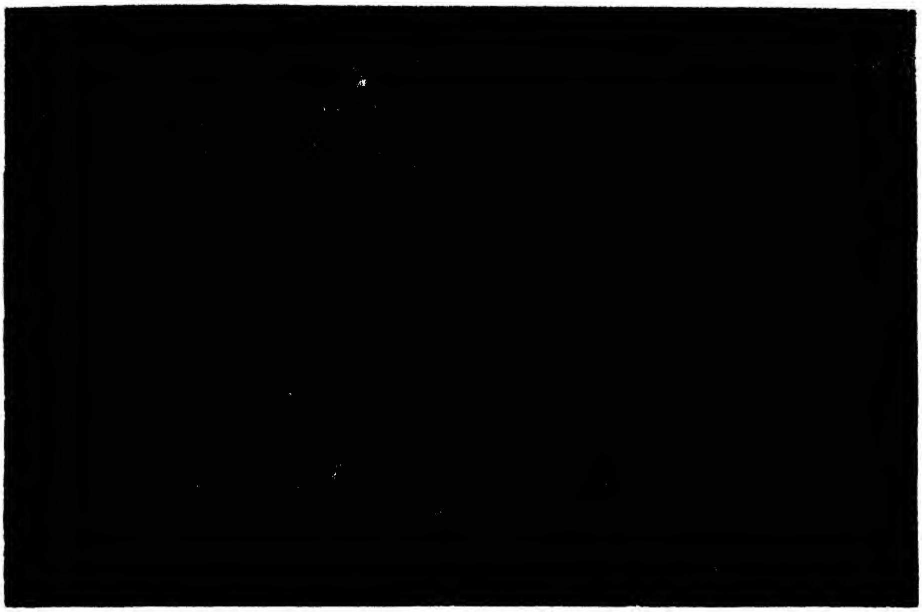
a. South end of Halemaumau January 23, 1917, looking southwest showing central lake and southern arm, and piled slabs from overflow of eastern rampart. Depression 50 feet.

b. North end of Halemaumau January 23, 1917, showing experimenters led by the Volcanologist with 200 feet of steel pipe on northeast point thrust into lake for sounding its depth. Depression 50 feet.

c. The men spaced out on northeast floor of Halemaumau with pipe disposed for sounding experiment.

d. Spatter rampart of northeast point with men carrying forward the pipe for its immersion. Liquid lava only 50 feet deep.

e. The same at beginning of recovery of pipe, which was trailed over the bank by the men walking back, the steel in a limp incandescent condition.



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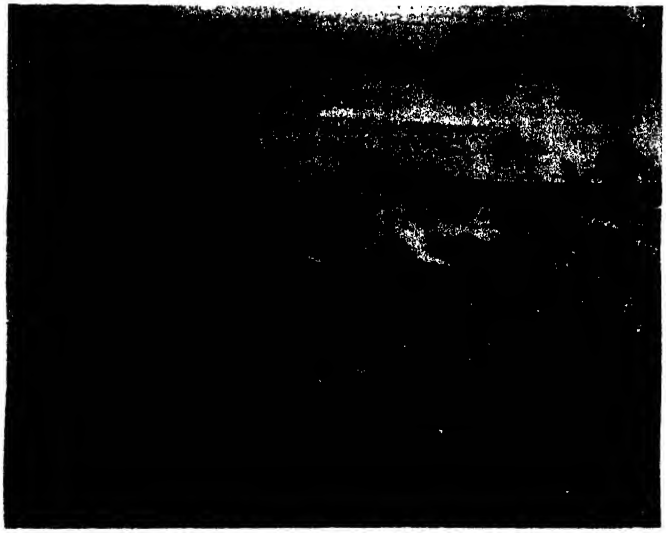

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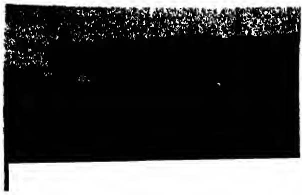

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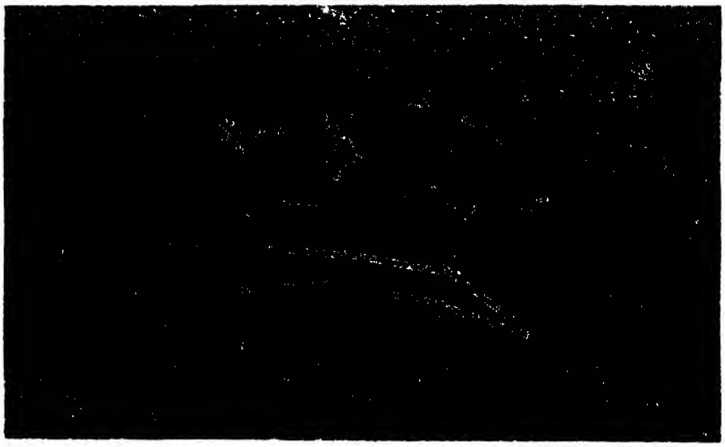

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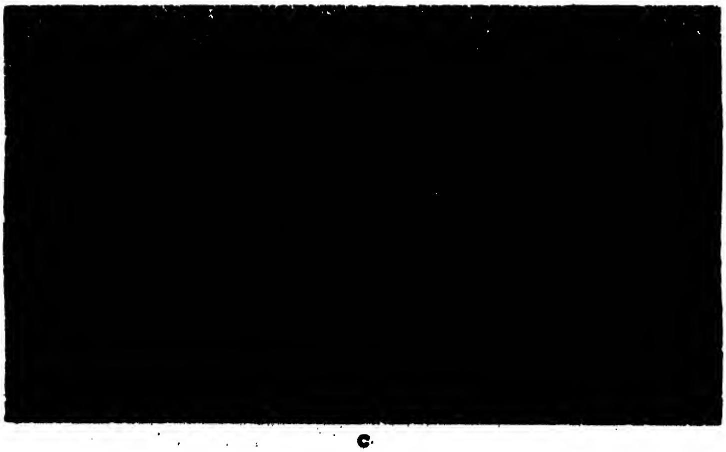


c

PLATE 22.—LAVA TEXTURE ON PIPES

a. Pipe immersed in edge of lava lake, imprisoned by heavy crust which made it impossible to withdraw it January 16, 1917, one of the temperature experiments.

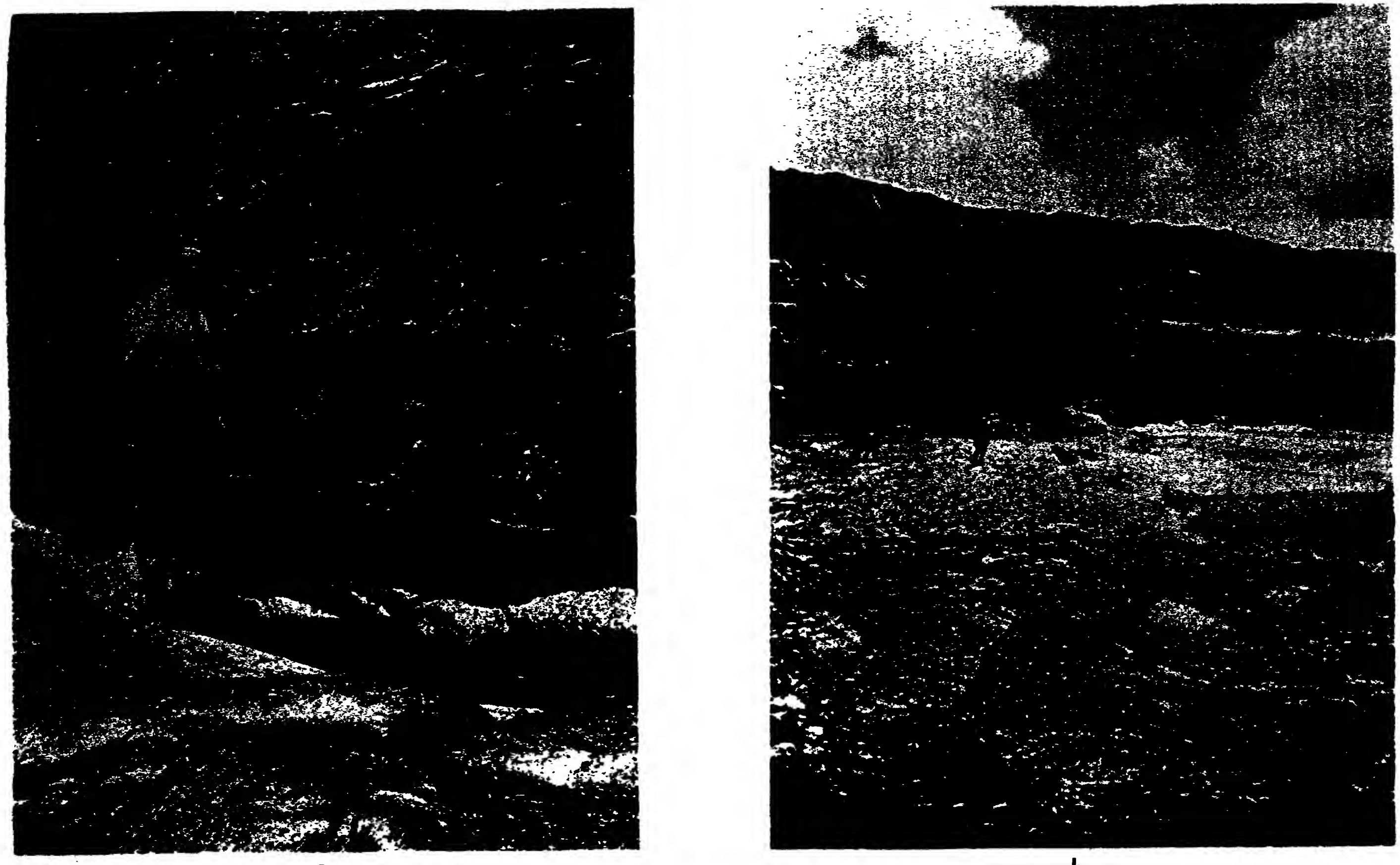
b. Surface pahoehoe of the liquid lava lake clinging to a pipe which had been withdrawn showing texture of surface lava, April 5, 1917.

c. Tip of pipe with seger cones inside immersed to a depth of 6 meters April 5, 1917, showing aa texture of the lava crystallizing on the pipe at that depth. Depression of lake 100 feet.

PLATE 23.—CRAG AND BENCH FEATURES

a. Base of east tabular crag showing aa texture, after uplift of the crag suddenly in one night. February 18, 1917.

b. East cove of lava lake where pipe experiments for temperature were repeated showing shore bench of higher level against wall of pit. April 5, 1917. Depression 101 feet.



a b

CRAG AND BENCH FEATURES 1917

a

b

c

Plate 24.—DETAIL OF CRAG MOTIONS

a. Interior of Halemaumau looking west showing preservation of high border bench after subsidence, the integrity of the subsided crags, inner bench around the crags from revival of inflow, and temporary negative movement of liquid lake relative to this bench March 30, 1917.

b. The same August 4, 1917, showing wreckage of east tabular crag, marked uplift of central crag, and relative subordination of northwest crag mass. Depression 114 feet.

c. Halemaumau looking northwest from southeast station November 16, 1917, showing effect of sudden uplift in one day of the southeast peninsula, exhibited flat in a and b. Central crag has become an impressive cathedral-like mass, and the northeast point has risen markedly. Depression 88 feet.

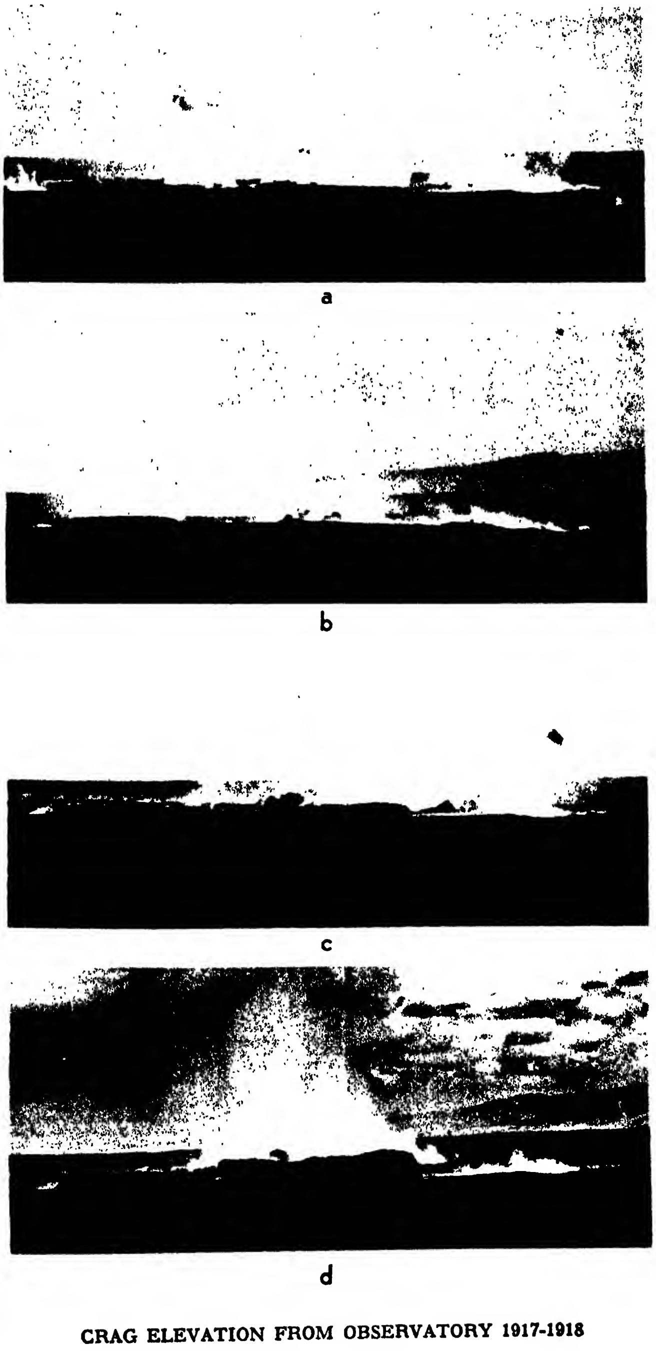
PLATE 25.—CRAG ELEVATION FROM OBSERVATORY

a. Halemaumau from Observatory December 17, 1917, depression of liquid lava 82 feet, crags appearing above edge of pit.

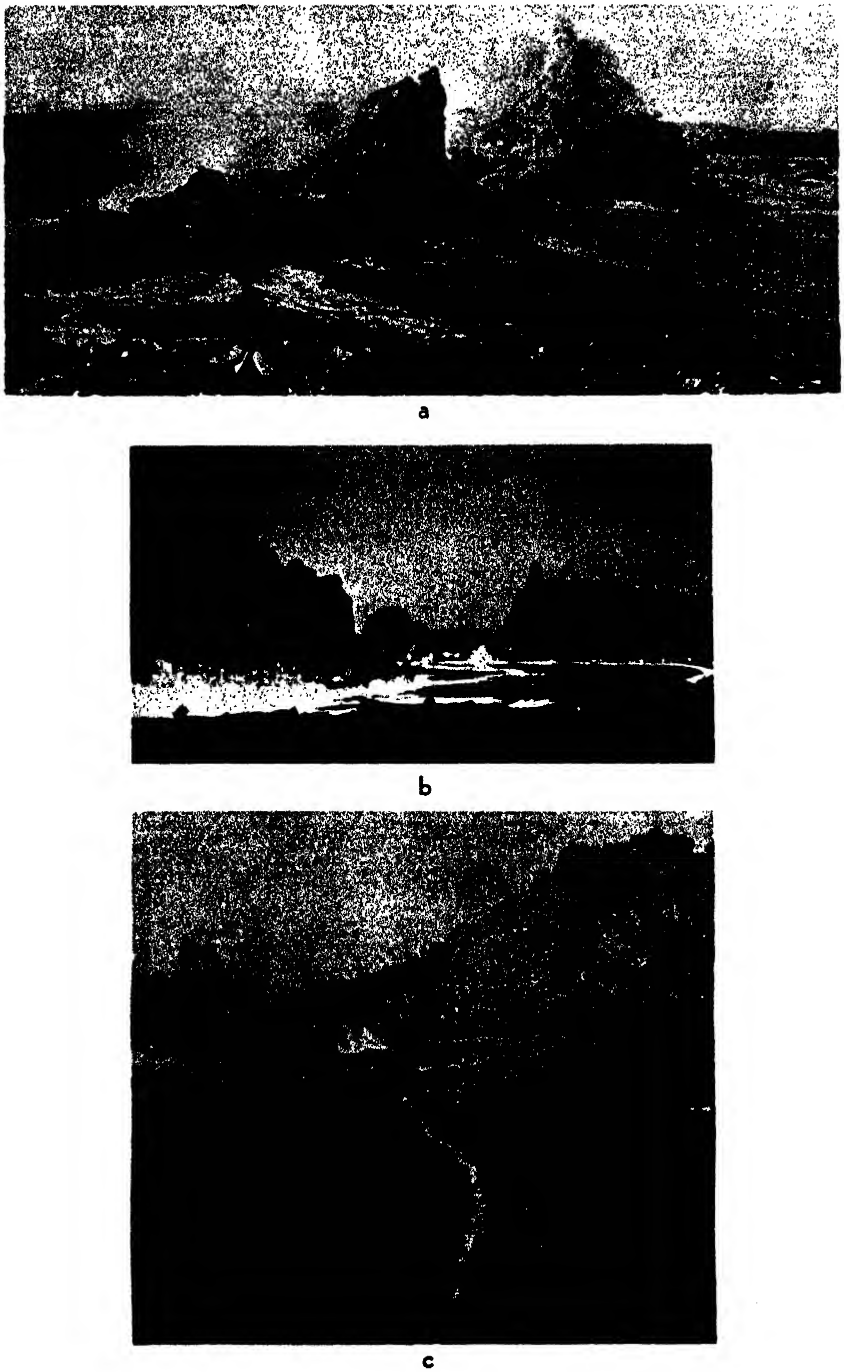
b. The same January 9, 1918, showing crags higher and fume diminishing. Depression of lake 58 feet.

c. The same February 8, 1918, showing crags higher, depression of lake 40 feet.

d. The same March 29, 1918, showing crags very high, depression of lake 12 feet. This series illustrates what was repeatedly measured with micrometer telescope from the Observatory to record the changing height of the lava column which carried with it both lava lake and crags in its fluctuation.



CRAG ELEVATION FROM OBSERVATORY 1917-1918



HALEMAUMAU OVERFLOWING TO KILAUEA FLOOR 1918

PLATE 26.—HALEMAUMAU OVERFLOWING TO KILAUEA FLOOR

a. From east station of Halemaumau rim showing southeast and central crags and a full lake in daytime January 23, 1918, depression 20 feet.

b. Night view of central lake from the east February 21, 1918, showing central crag, the old west crag mass, and the east pinnacle.

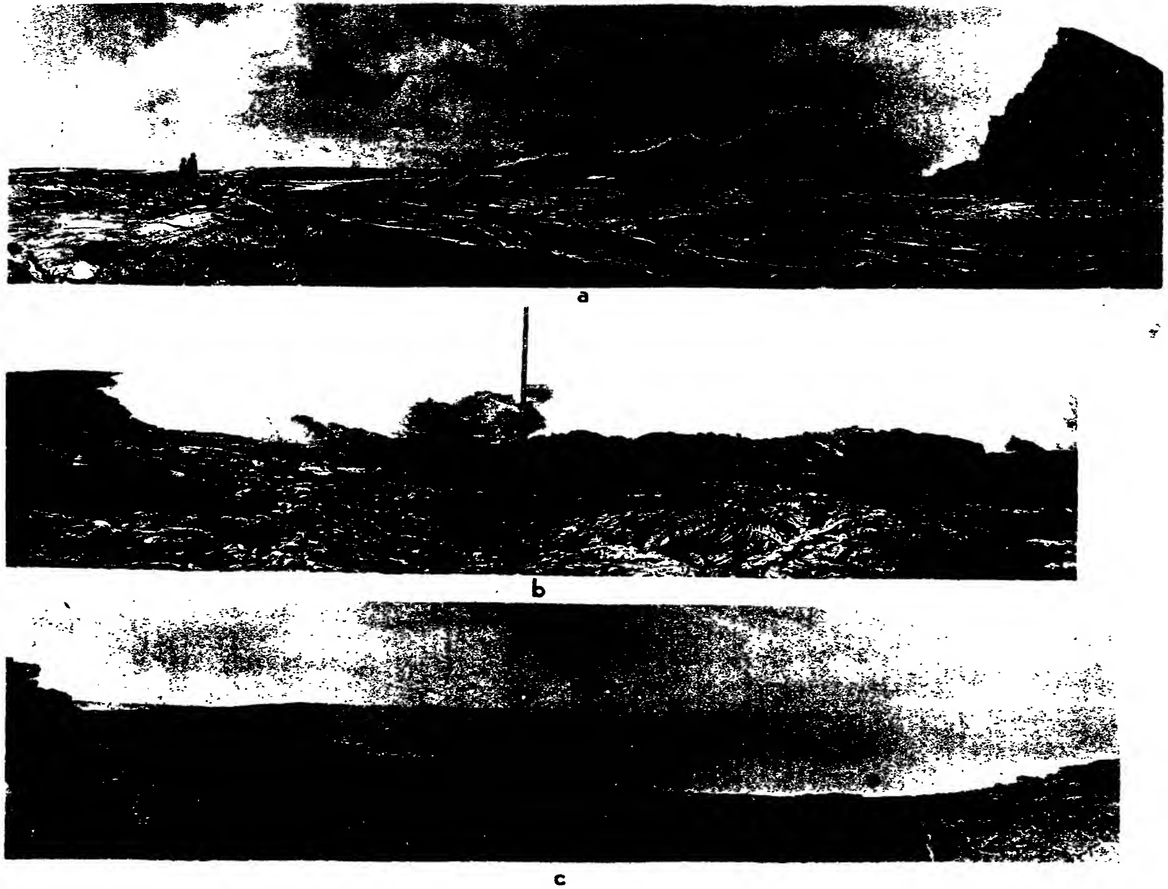
c. Looking north at southwest pond of Halemaumau overflowing showing in foreground characteristic medial festoons and side curtains of a pahoehoe stream. January 23, 1918, depression 20 feet.

PLATE 27.—DEPRESSION AFTER OVERFLOW

a. Halemaumau full to the rim, the figures shown standing at the east rim station. Crags now far above rim, and overflows in progress which covered the road terminus southeast of the pit. February 23, 1918. Depression of liquid lake below datum rim station northeast, 5 feet.

b. The rapid sinking in progress March 31, 1918, leaving the overflows as added to Kilauea floor as shown in the foreground. Crags and lakes lowering together so as to preserve topography of top of lava column. Depression 100 feet.

c. The same scene April 5, 1918, showing that the lava column has sunk beyond the angle of view. Depression 237 feet.



DEPRESSION AFTER OVERFLOW 1918

a

b

c

PLATE 28.—PRESSURE RIDGE PIT-MARGIN

a. This plate shows three stages of a process that squeezes into pressure ridges portions of the rim of Halemaumau. In (a) August 8, 1918, a trickle flow is shown pouring from north arm of lake into northeast wall valley after the flat floor over epimagma was tilted up at high angle over tumefying forces below. Depression of lake 62 feet.

b. The same wall-valley August 15, 1918, after filling with a large crusted wall-pool. (a) was looking northwest, this is looking southeast. The stage is now set for any further uptilting of the crags on the right to exert an enormous thrust against the pit wall on the left after the wall-pool solidifies. Depression of lake 30 feet.

c. This is just what happened on the southwest side of Halemaumau March 3, 1918, here shown as a pressure ridge 15 feet high with the pit fill on its right, the outer Kilauea floor on the left, and fresh sudden overflows of Halemaumau in foreground. The view is looking west from outside of the south Halemaumau rim. Pressure ridges of this type are formed in a few days.

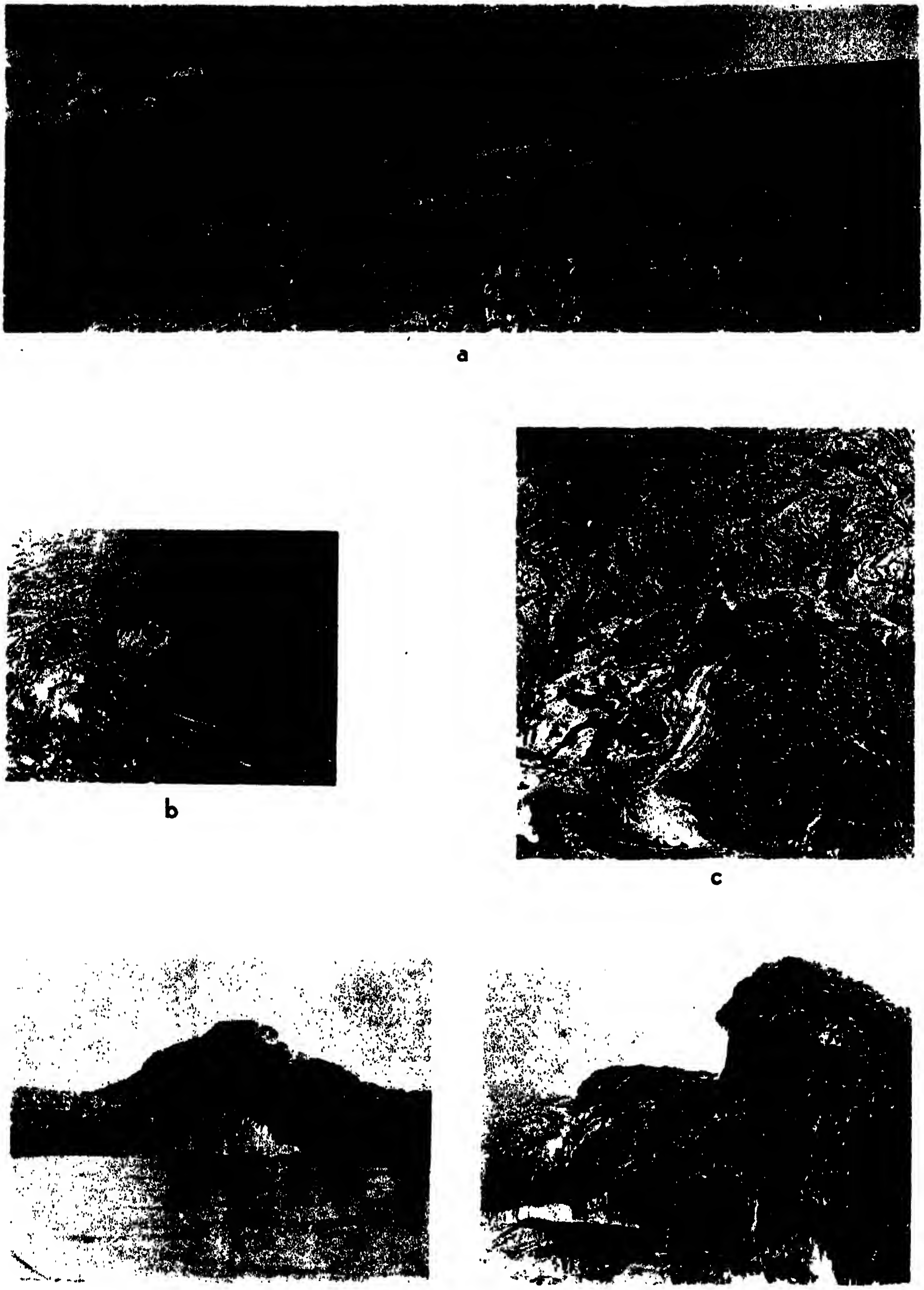
PLATE 29.—DROWNING OF CRAGS

a. Halemaumau looking west December 20, 1918, depression of lake 57 feet. An exceptional flood of liquid lava had leveled off the pit floor drowning the crags, replacing several of the ponds with source cones, leaving a small main lake as shown, and only the central crag unsubmerged.

b. Halemaumau floor looking toward the east shelter showing northeast bench of 1894 filled with 1918 overflows and exhibiting a crusted full lake on the northeast floor of the pit. The rapid rising of quiet lava without border fountains here produced a topography like Wargentin on the moon. The margins of this oval lake were simply overflow terraces. December 25, 1918, depression of main lake, 72 feet.

c. Halemaumau, the west wall of Kilauea, and Mauna Loa looking west December 24, 1918, depression 72 feet. This shows the features of (a) and (b) assembled, and the jumbled pahoehoe overflows from several sources constantly adding to the semisolid pit floor. The crag process for the time has come to an end. In November there were more outflows on the Kilauea floor to the north while Halemaumau was in this condition, but these welled up external cracks and even cascaded back into Halemaumau over its north rim.

DROWNING OF CRAGS 1918



LAVA FOUNTAINS AND OVERFLOWS 1918-1919

PLATE 30.—LAVA FOUNTAINS AND OVERFLOWS

a. Southwest rim of Halemaumau overflowing January 19, 1919, depression of lake 29 feet. With Halemaumau full to overflowing through most of 1919, depressions were measured relative to some survey station that persisted, but rearrangement of the datum stations became necessary, as all but the west high cliffs were overflowed, and the latter were lifted by intumescence. This picture shows the new slope of overflows southwest and the flat inner floor of the full pit on the right.

b. A viscous fountain like a large bubble on the well of north overflow outside of Halemaumau November 2, 1918.

c. The west pond cone of July 31, 1919, pouring out a small flow of incandescent pahoehoe and lifting a sector lid in pulsations.

d. Large spatter grotto at edge of main lake February 6, 1919, photographed while rapidly surging with a speed portrait lens.

e. A similar grotto from the side showing driblets of dripping lava while the fountains surge and pound beneath.

PLATE 31.—OVERWHELMING OF STONE SHELTER

a. Halemaumau now a hill with three lakes in clover-leaf pattern on its crest as seen from the east looking across Kilauea floor. April 17, 1919.

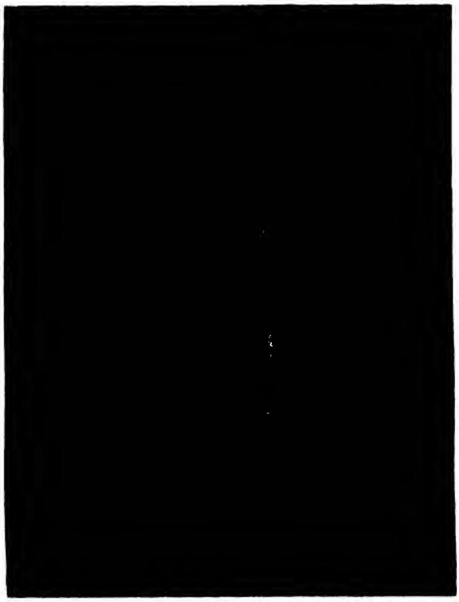
b. East shelter of Halemaumau rim with lava flows on the right about to overwhelm it February 2, 1919. In background the instrument hut several hundred feet east of Halemaumau, burned by overflow in March 1921.

c. The full Halemaumau and its dome profile at night as seen from Observatory February 12, 1919, showing the glow of the three lakes.

d. East shelter from the back February 14, 1919, with lava lakes in the background sending pahoehoe flows into the foreground and gradually burying the shelter. The level sky line is the top of the Halemaumau dome.

a

b



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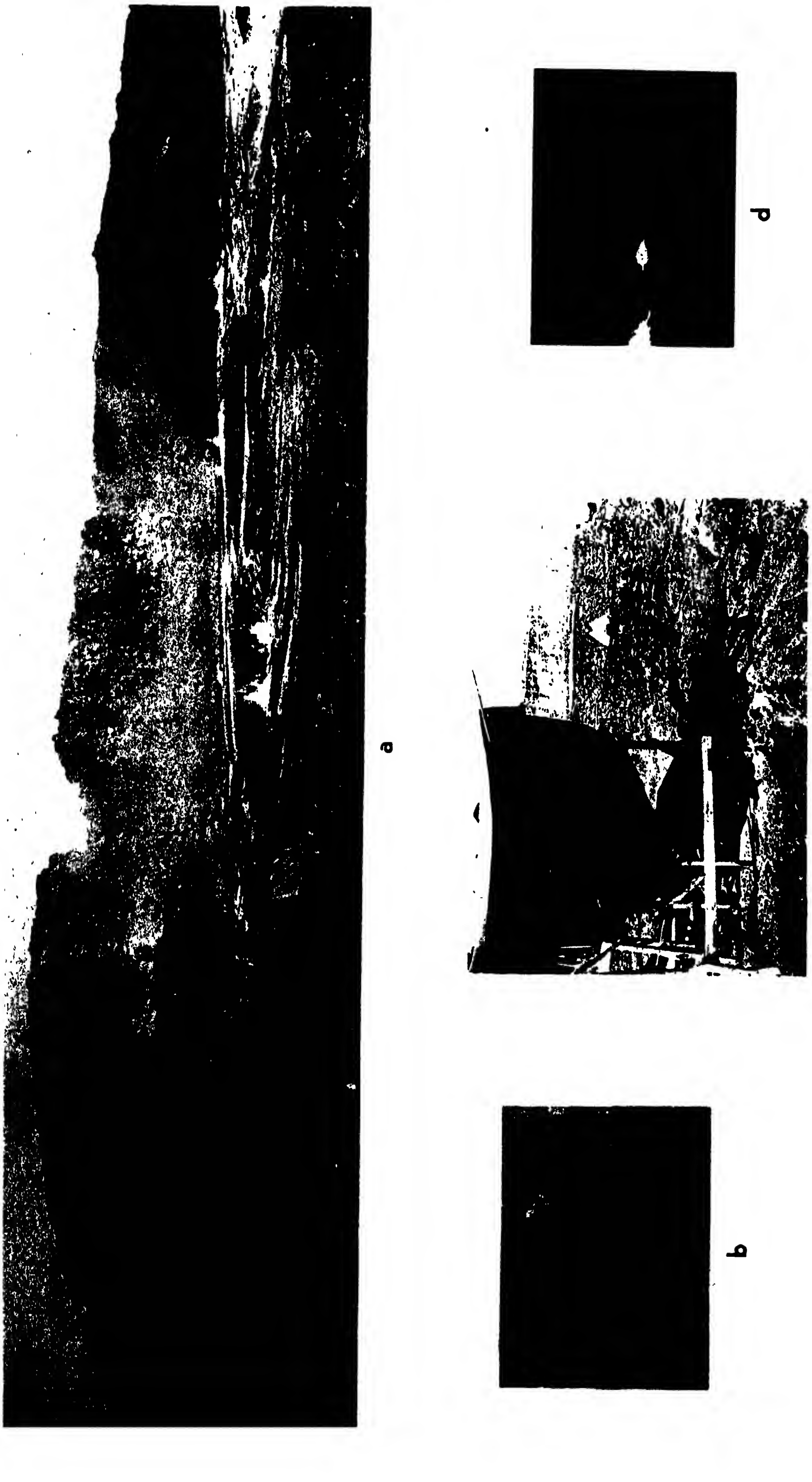


LAVA-TIDE SURVEYS 1919

PLATE 32.—LAVA-TIDE SURVEYS

a. Looking south into the north lake of Halemaumau in May 1919 at about the position of transit shelter later used for measuring the lava tide. The people shown are entirely inside the pit standing on the dome surface of the lava column itself. The pit rim is mostly buried by the mushroom cross section of the lava column, the outer fringe of the mushroom being crusted overflows.

b. The first transit shelter in July 1919 as used for observations on datum station, on epimagma monuments, and on lake-border grottoes every 20 minutes for a month. North edge north lava lake, Halemaumau.

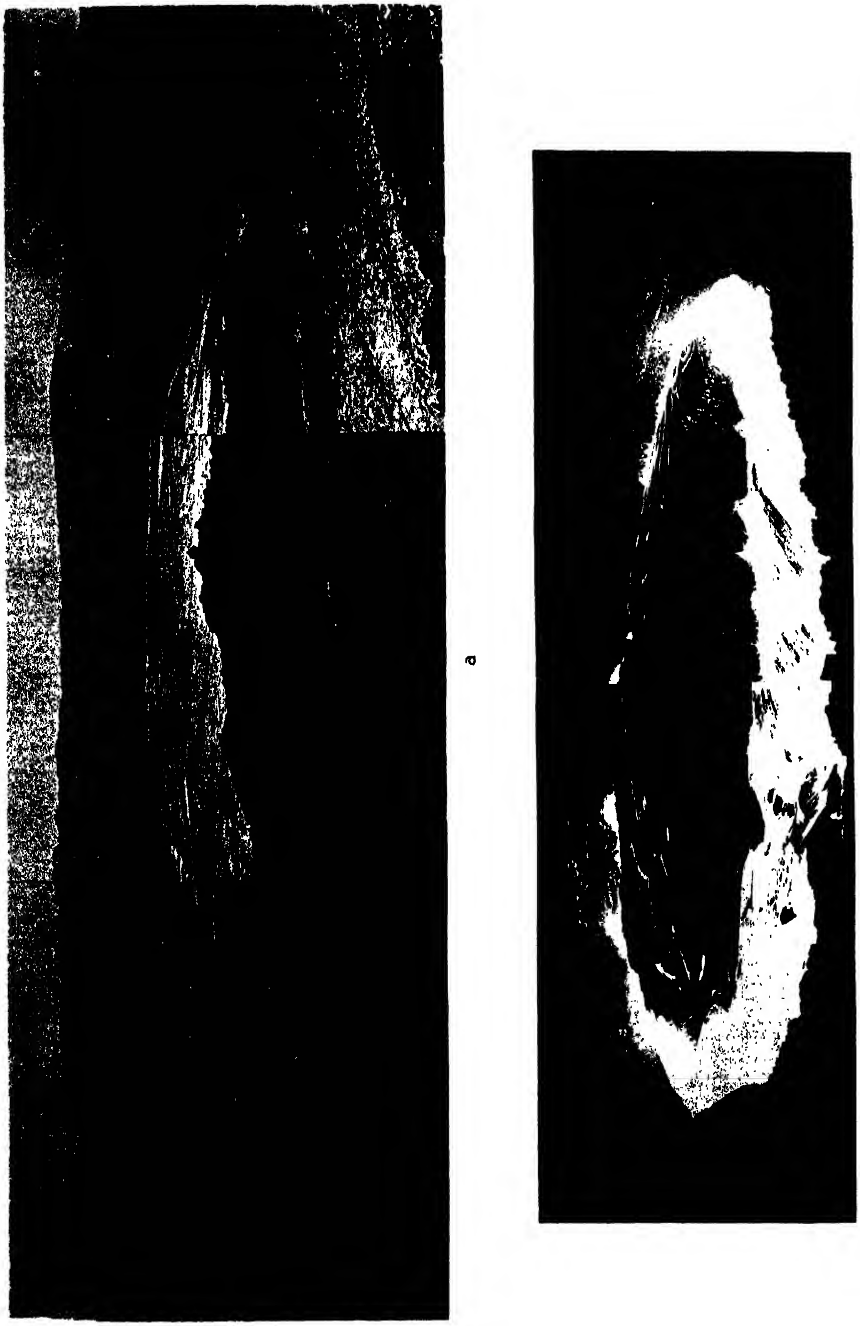
c. Second transit station with transit in position August 17, 1919, with camping tent in background.

d. Night scene same as (b), showing transit tent by lantern light, and the two fountains used for measurement points July 1919.

PLATE 33.—RING ISLAND OF EPIMAGMA

a. Halemaumau looking south December 16, 1919, depression 148 feet. Plug of the subsidence of November 28, lifted bodily in funnel shape, violent gas activity of fountaining in ring-pool which is deep, shallow lagoon in center which is quiet. Margin scar of November high level shown around upper edge of pit.

b. December 11, 1919. Halemaumau looking south-southwest, depression 187 feet. Night scene nearly identical with (a), demonstrating greater activity of ring-pool, convectional streaming of crusts from lagoon outward to western source fountains, and meeting of ring-pool currents in sink-hole in foreground. This was the most rapid rise of the inner lava column ever recorded by Observatory, the average being about 30 feet per day.



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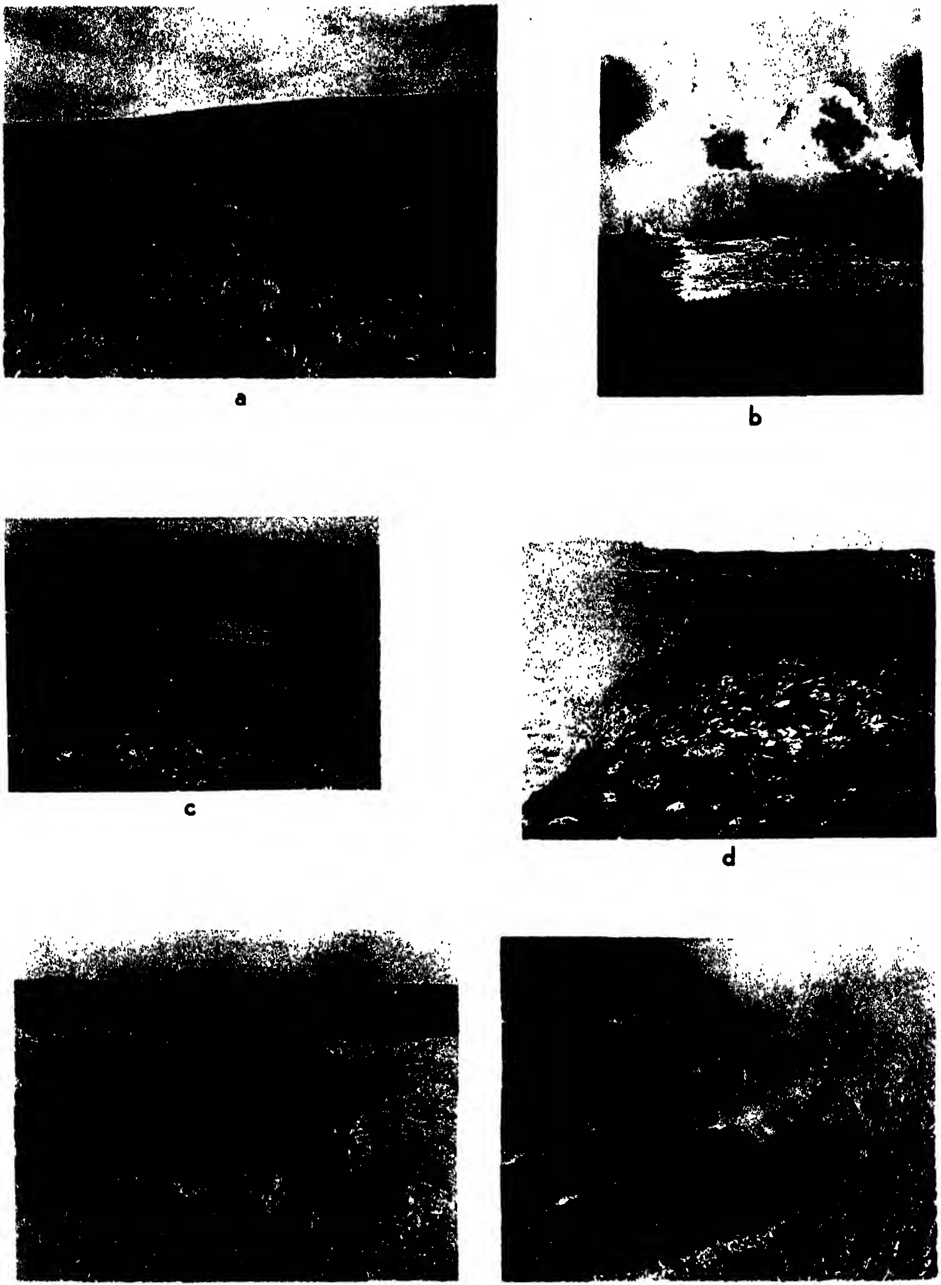
RING ISLAND OF EPIMAGMA 1919



a

b

c

d

e

f

HALEMAUMAU AND KILAUEA-FLOOR OUTFLOWS 1919-1920

PLATE 34.—HALEMAUMAU AND KILAUEA-FLOOR OUTFLOWS

a. Source cone and torrent of pahoehoe lava from fissure back of north rim Halemaumau May 6, 1919. Spatter grotto at source, swift torrent pouring west, picture looking southwest, Halemaumau on the left not shown. Depression of lakes 53 feet.

b. Halemaumau and west floor of Kilauea Crater in afternoon light, November 28, 1919, showing large fill of new pahoehoe with liquid lava flowing under it in tunnels filling north corner Kilauea Crater 60 feet deep. Source cones as at (a), cracks outside of Halemaumau. Halemaumau on extreme left. This was the day of the sudden intense collapse which happened about 2:00 a.m.

c. Ground northwest of Halemaumau with formerly level concrete seismograph pier in foreground. Fresh flows west of pit. Halemaumau outside of picture on the left. Intense tilting due to swelling up of Halemaumau dome along with outside Kilauea floor. August 17, 1919. Depression of lakes 30 feet.

d. North corner of Halemaumau looking west (photo fits right side of Plate 33 a) December 16, 1919. Depression of lake 148 feet. Shows aa consistency, under slabs of pahoehoe, of the epimagma that slumped down during the subsidence of November 28.

e. Lee's pit in southern floor of Kilauea Crater with frozen cascade of December lava of 1919. January 8, 1920, the foreground 1894 lava and one of its channel caverns.

f. Halemaumau January 1, 1920, during subsidence that followed the December rise showing ring island and north crags crowding out the ring pool by subsidence of the funnel-shaped epimagma plug. Looking south-southwest across northwest side of bottom. Depression 255 feet.

PLATE 35.—KAU DESERT RIFT BREAKING OPEN

a. Along new Kau Desert rift crack 4 miles from Halemaumau looking southwest, December 22, 1919. First stage with opening crack steaming.

b. Same region in Kau Desert looking up the rift northeast, December 22, 1919. New cracks sprung open with crusted lava of pahoehoe type welling up inside. The man has his hand on a fresh spiracle of black basalt. Steaming of hot lava behind him.

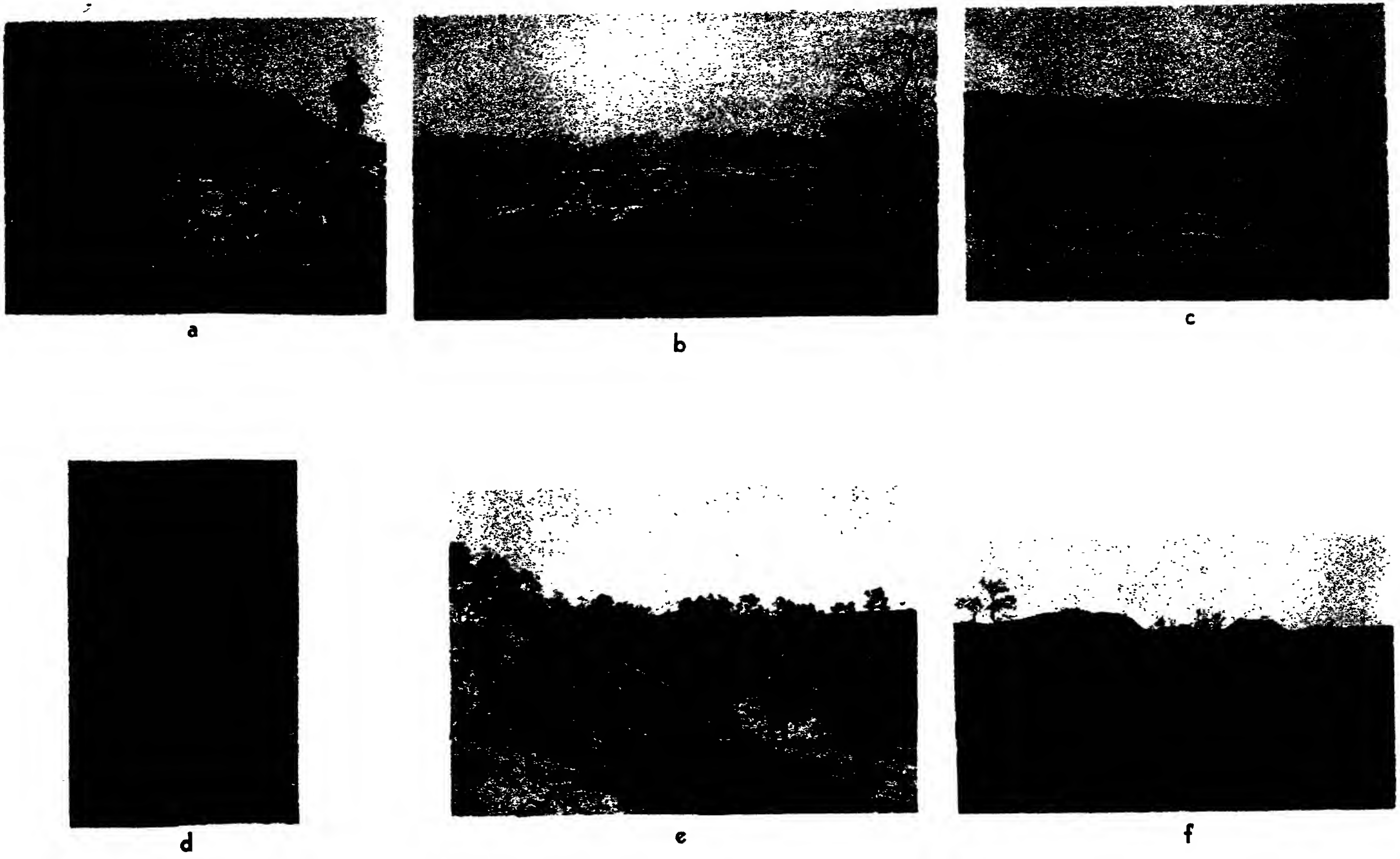
c. December 26, 1919. Third stage of outflow from rift cracks in Kau Desert. About 9 miles from Halemaumau southwest. Partly congealed spreading lava penetrating and burning the forest and building a slag heap over a crack amid sand dunes. Fresh tongue of pahoehoe burning shrubs.

d. The same dune land country of Kau Desert looking up the rift showing newly opened crack from which lava welled out at this time. December 28, 1919.

e. Same region looking along cracks trending down the rift belt covered with a heap of fresh lava about 80 feet high, the edges of which are shown. Photo shows edges of this heap. December 28, 1919.

f. Marginal puddle of this lava spreading so that during this day, December 28, 1919, the people shown had their footprints covered as indicated in foreground.

KAU DESERT RIFT BREAKING OPEN 1919



MAUNA IKI AND ITS FLOWS 1919-1920

Plate 36.—MAUNA IKI AND ITS FLOWS

a. Normal pahoehoe lava from Kau Kesert rift December 24, 1919, first stages of building Mauna Iki.

b. Delta torrent of Mauna Iki construction by terraces December 25, 1919. The torrents are pouring down the rift from right to left, and backing up in terraces to the region of maximum opening of the source cracks, where a dome surface with confined lakes gradually formed, reaching a height of 125 feet above previous country level.

c. A long flow that pushed beyond the main center at Mauna Iki, which was 6 miles from Halemaumau, and this flow, by stirring and crystallization, is shown as aa at its edges, pahoehoe in its channel. December 31, 1919. The flow pushed about 5 miles below Mauna Iki.

d. Pahoehoe cascade running out through a channel in an earlier pahoehoe front of slabby lava January 12, 1920, Kau Desert outflows.

e. A graben fault channel showing side of downsunken block in right foreground along southwest-trending Kau Desert rift December 25, 1919. This channel was later followed by the flow of (c) and (f), which ruthlessly pushed the trees down one by one and swallowed them in the flood of slag.

f. The aa flow of (c) and (e) completely stirred to solidification in the crystalline condition without any glassy tendency. December 31, 1919. Kau Desert looking east.

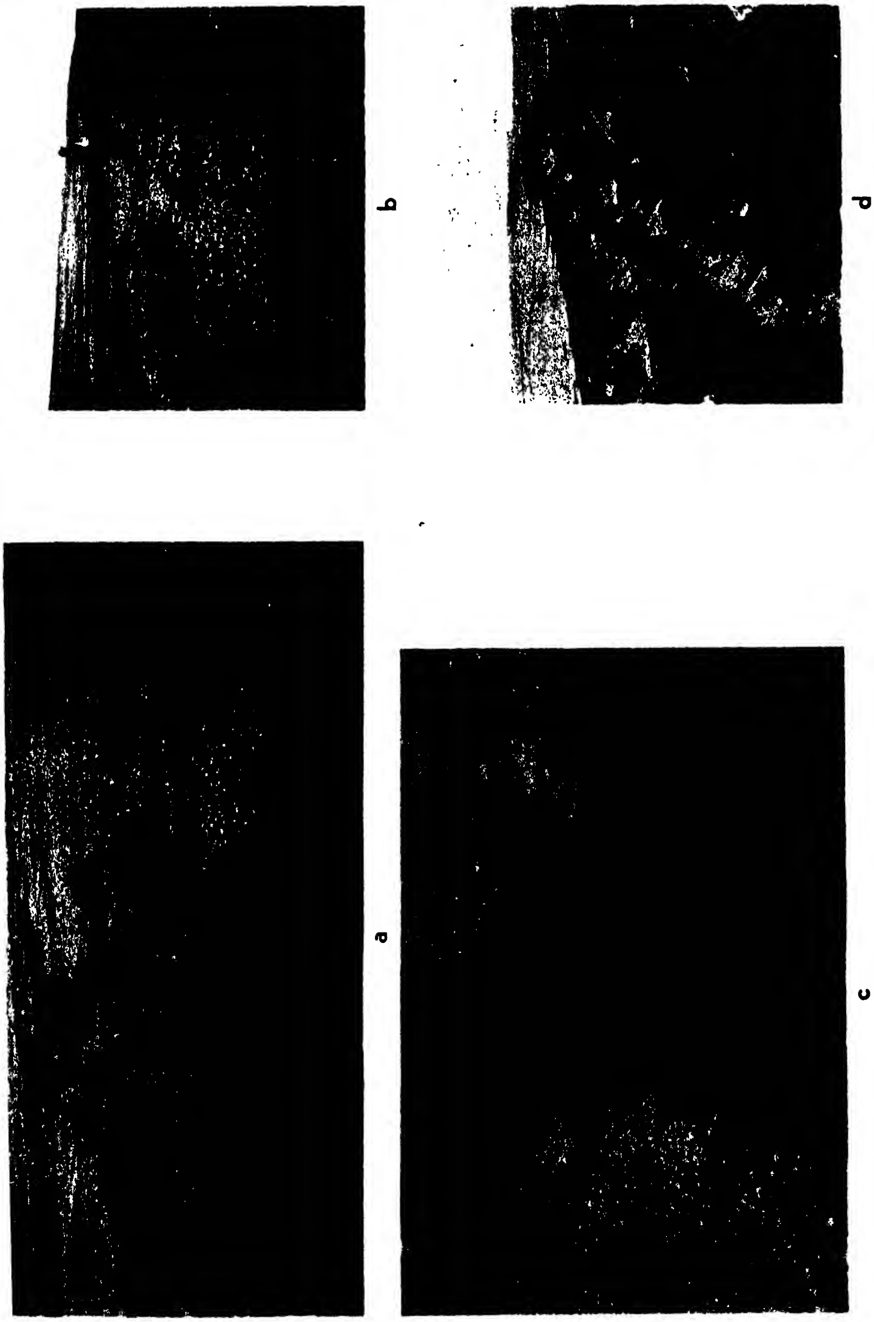
PLATE 37.—GAPING CHASM OF KAU DESERT RIFT

a. The opening of Kau Desert rift December 22, 1919, immediately southwest of Kilauea Crater showing miniature graben phenomena.

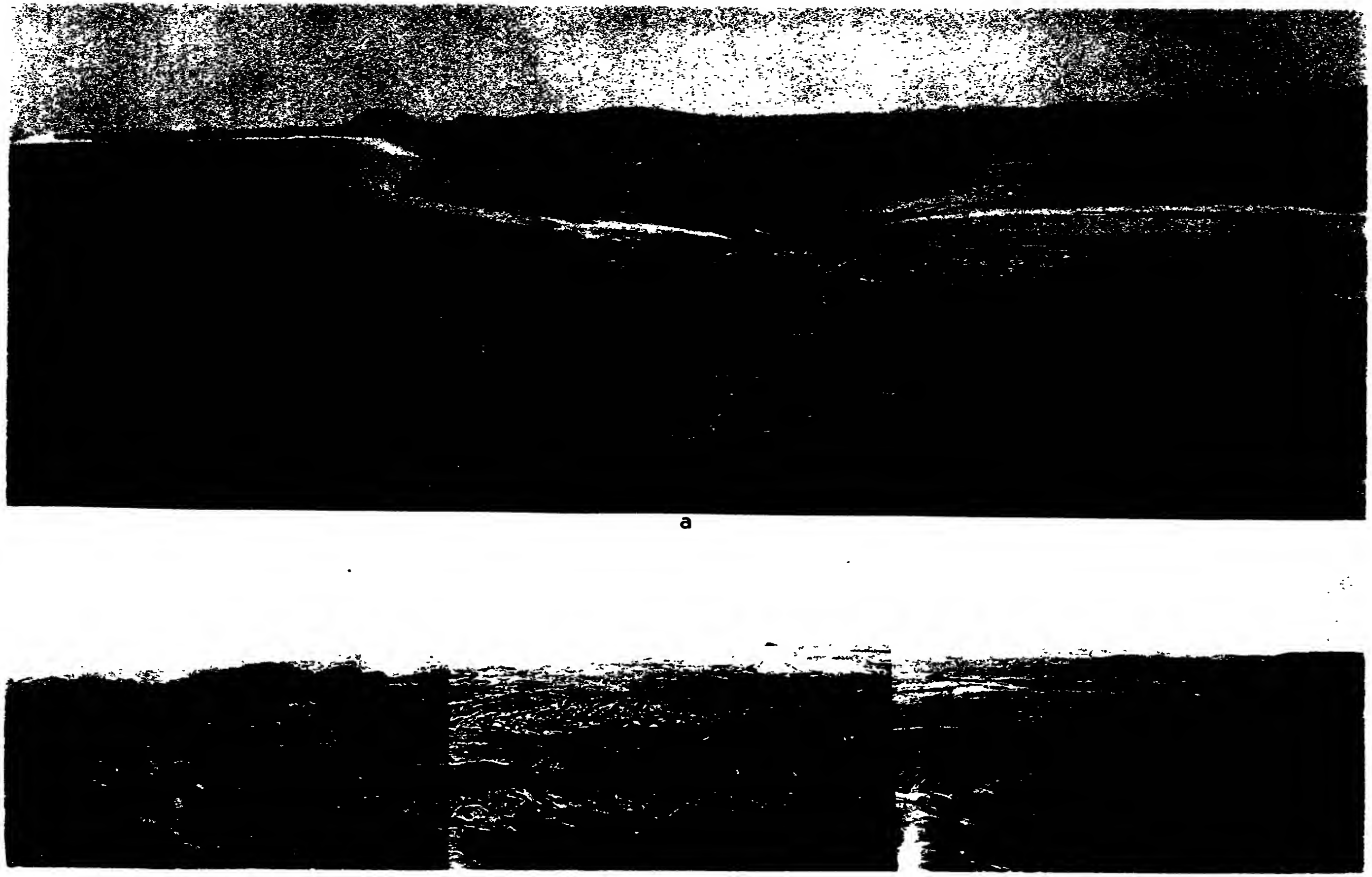
b. A portion of the newly opened Kau Desert rift southwest of Kilauea photographed February 3, 1920, showing the nature of fresh cracking similar to (a) but arrested in an earlier stage.

c. The great rift opening 300 meters southwest of Kilauea December 22, 1919, gaping 10 to 15 feet wide with sluggish pahoehoe trickling along its bottom about 60 feet down. Stages of opening this chasm during 2 weeks as in (b) and (a).

d. Same chasm as (c) photographed July 16, 1921, showing permanent condition of the opening up which hot vapor rises.



GAPING CHASM OF KAU DESERT RIFT 1919-1921



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MAUNA IKI TERRACES 1920

Plate 38.—MAUNA IKI TERRACES

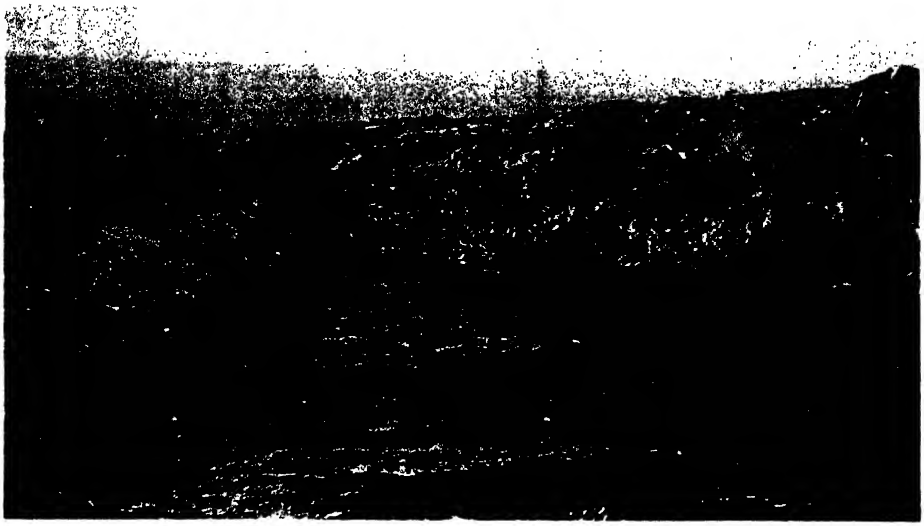
a. Pahoehoe torrent pouring southwest toward distant Kamakaia Hills about January 1, 1920, showing terrace formation and downslumping of escarpments along the rift in the incipient Mauna Iki hill. Cascade pouring over one of the terraces. The ejection of this long lava flow caused an amphitheater circular in plan to slump in the crest of the low dome already formed.

b. Where (a) looked out of the horseshoe of the amphitheater showing its western cliff, this picture, made January 14, 1920, shows Mauna Iki in similar condition with the eastern point of the confining crescent indicated as a cliff on the left.

Plate 39.—PAHOEHOE AND AA CONTRAST

a. A pit in the Mauna Iki region February 14, 1920, receiving a cascade of pure pahoehoe lava.

b. The frontal region of advancing incandescent aa lava flow February 23, 1920, Kau Desert, about 11 miles from Halemaumau. Front of flow about 10 feet high. Shows an incandescent cavernous space in the pasty front which was crunching its way forward as a stiff pudding with boulders breaking off and dropping down.



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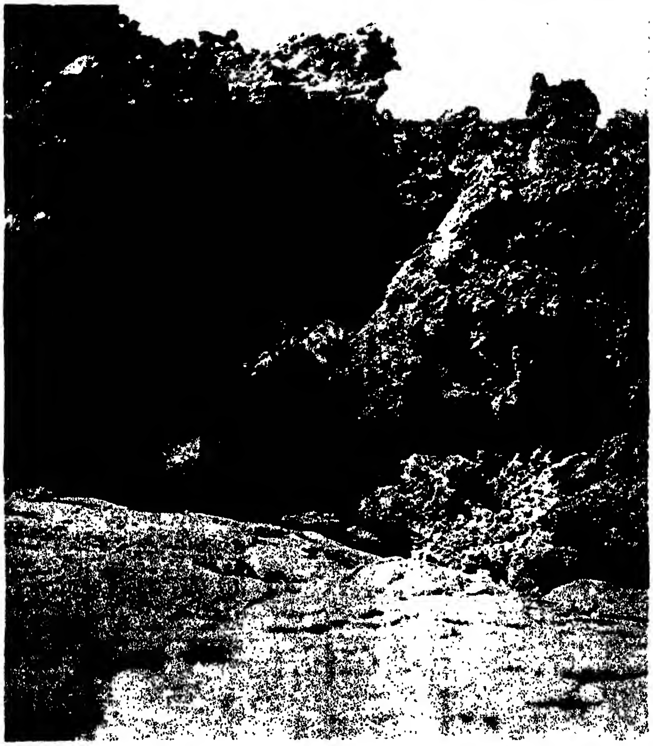

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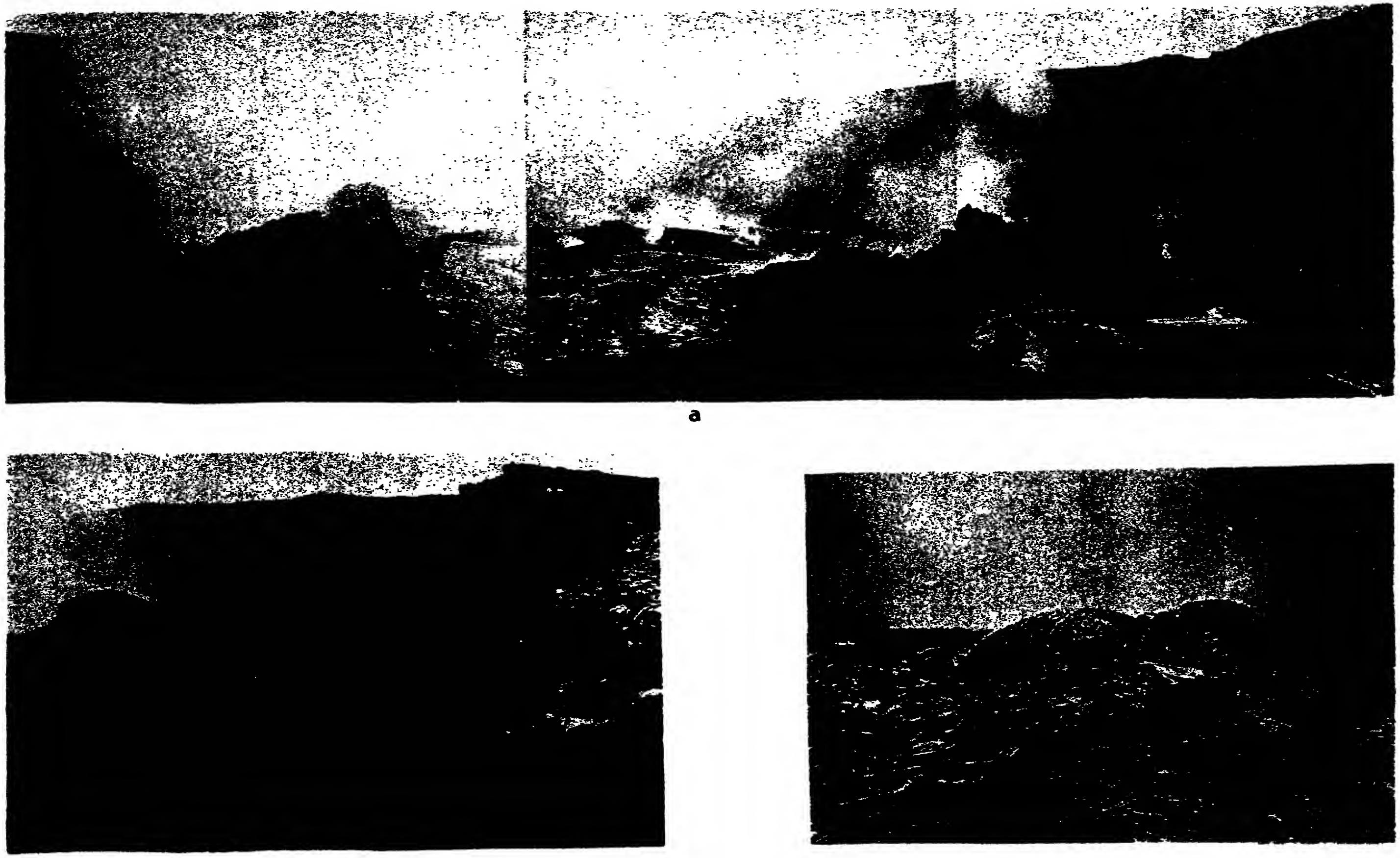
PAHOEHOE AND AA CONTRAST 1920



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FEATURES OF PIT AND OUTLYING RIFT CRACK 1920-1921

Plate 40.—FEATURES OF PIT AND OUTLYING RIFT CRACK

a. Interior of Halemaumau looking southwest September 7, 1920, showing the rising lava column after Kau Desert flows ceased. The rising crags represent the disrupted remnants of the annular epimagma of Plate 33. Depression 265 feet.

b. Northwest pool and crag of Halemaumau April 8, 1920, showing general condition of pit during Kau Desert flows with less recovery than in (a). Depression 166 feet. The crag is a remarkable example of at least 12 stages of hinge uplift of epimagma shown by the radial disposition of uplifted shore lines hinged against wall of pit and lifted by central tumescence of epimagma.

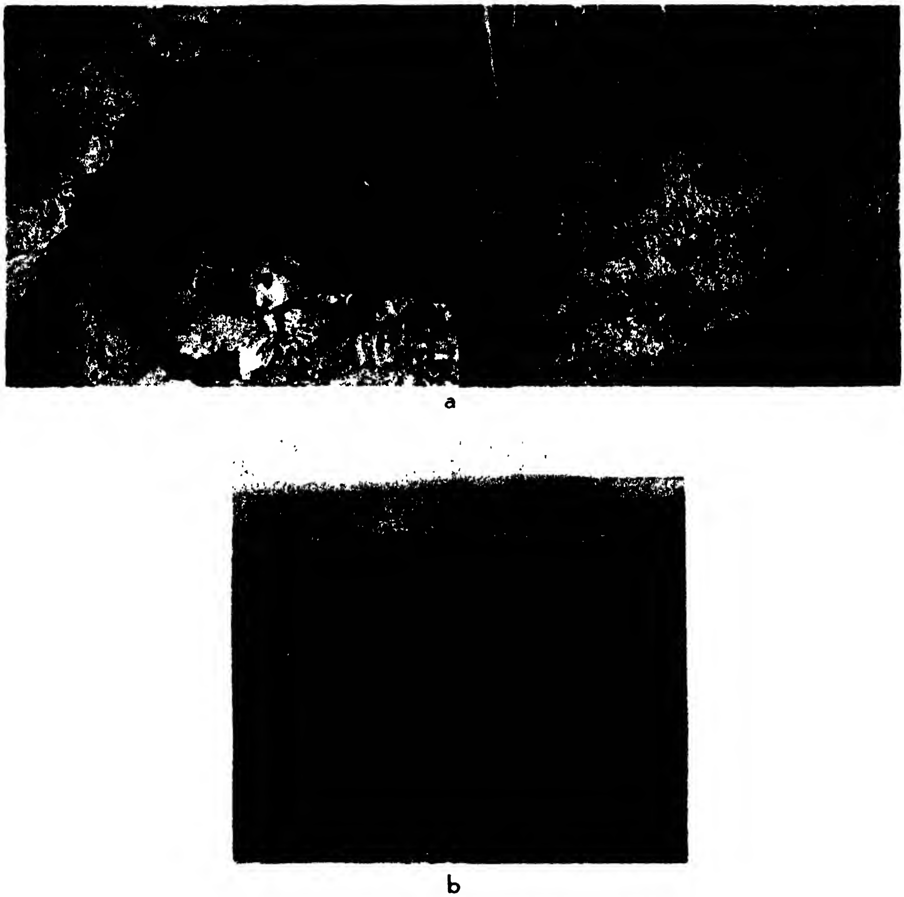
c. The recovery of March 20, 1921, at Halemaumau, showing fountaining dome of liquid pahoehoe at southwest cone of the Red Solfatara 500 feet outside of Halemaumau rim over a well in the great rift. Fountain covered with expanding vesicles, orange incandescent, continuous flow like an artesian well with a cascading channel leading to the left.

PLATE 41.—FEATURES OF MAUNA IKI

a. Interior of the large lava tunnel left by the channel of the prolonged pahoehoe flow of Mauna Iki which pushed southwest for several months under a cover of its own crust to beyond Kamakaia. September 3, 1921, showing cavern detail of worm and walking-stick stalactites on the right and a caved-in portion with covering of sulphates, scale shown by the human figures.

b. A small opening along the Kau Desert cavern of 1920 which remained excessively hot for months, lined with white and yellow sulphates. July 18, 1920.

c. Summit of Mauna Iki July 18, 1920, showing lava pit and lake which was one of several depressed into the flat top of the heap along the course of the underlying rift. This heap was 125 feet high, 2 miles long, and a mile wide.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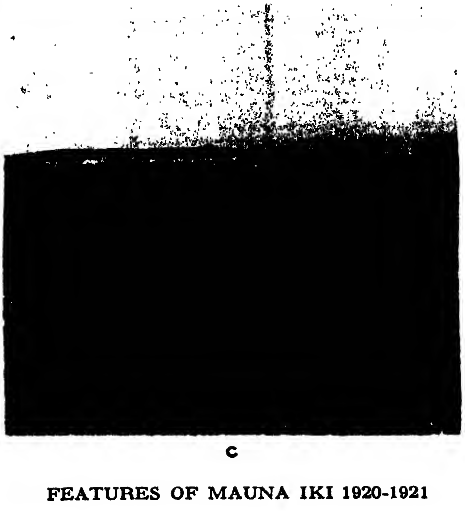
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FEATURES OF MAUNA IKI 1920-1921

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PLATE 42.—KAU DESERT IN 1823

a. and b. These two photographs of September 8, 1920, introduced here because they represent the Kau Desert rift opening 1823 about 20 miles from Kilauea, where a graben chasm revealed the extraordinary ball lava shown. Chasm opened to lower the lava that had been overflowing the crack, revealing the cross section. Balls perfectly smooth, of many sizes in matrix of pahoehoe lava. Balls do not show on upper surface of lava flow. Each ball concentric layers about a rock kernel. Mechanism appears to have been a churning of rock kernels in the lava-filled crack, the kernels being talus, and spherical concretions of glassy lava were thus aggregated. A revival of outflow carried these out as a conglomerate within incandescent matrix congealing on the surface as ordinary pahoehoe. The revelation of cross section shows the pudding-stone structure. The balls are as smooth as a sea-worn pebble but totally different in their concentric structure.

PLATE 43.—PANORAMAS OF HALEMAUMAU

a. Halemaumau looking south-southwest May 23, 1920, showing one stage in the fluctuation of crags, fume, and chaotic condition of lava lakes in Halemaumau during the outflow in the Kau Desert. Depression 168 feet.

b. Halemaumau looking south-southwest December 17, 1920. Depression 106 feet. Strong rising continued in autumn of 1920 following condition shown in Plate 40 (a) with wall-crack ponds recalling the annular lake of December 1919 and the crag masses in the middle representing an uplift of the epimagma body. In general the epimagma is again being drowned by excess of pyromagma.

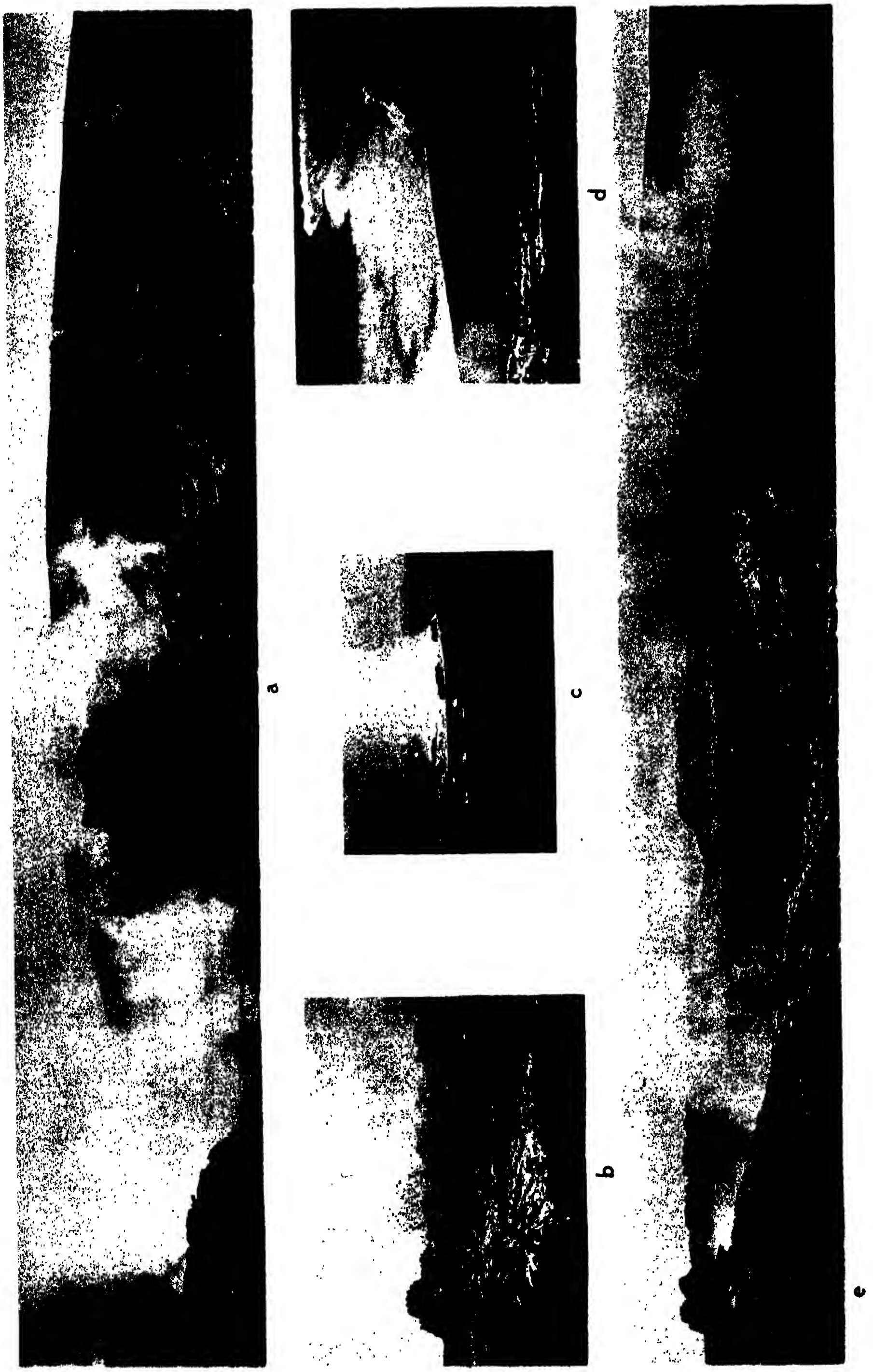
c. Halemaumau looking south, December 31, 1920, depression 20 feet. The process of rising shown in (b) was continued until the lava column was nearly level with the rim of Halemaumau with central crag standing well above the rim.


a

b

c

PANORAMAS OF HALEMAUMAU 1920



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GREAT MARCH RISING 1921

PLATE 44.—GREAT MARCH RISING 1921

a. Halemaumau looking southeast March 10, 1921, showing temporary lowering after the high levels of December–January. Depression 108 feet. This shows a jumble of crags with diversified shore marks left by the liquid lava and a high level marginal bench. In the background on the right is the jagged southern pressure ridge of 1919.

b. Halemaumau looking SW March 19, 1921. Depression 5 feet. Sudden rise from (a). Spatter wall built against pressure ridge, foreground torrent into southeast sink-hole. Overflow period.

c. Whole of Halemaumau from west bluff of Kilauea March 25, 1921, showing crags as islands and pit brim full.

d. Halemaumau looking west March 19, 1921, with unusual convection cloud over Mauna Loa summit suggesting sympathetic gush there.

e. The same view March 21, 1921, when lowering of the liquid lava with cascades into vast sink-holes at the southeast took place. Depression of liquid indeterminate. Bespattered pressure ridge shown on the left, and the crags left partly as mushrooms of fresh pahoehoe all coated with masses of black glassy lava.

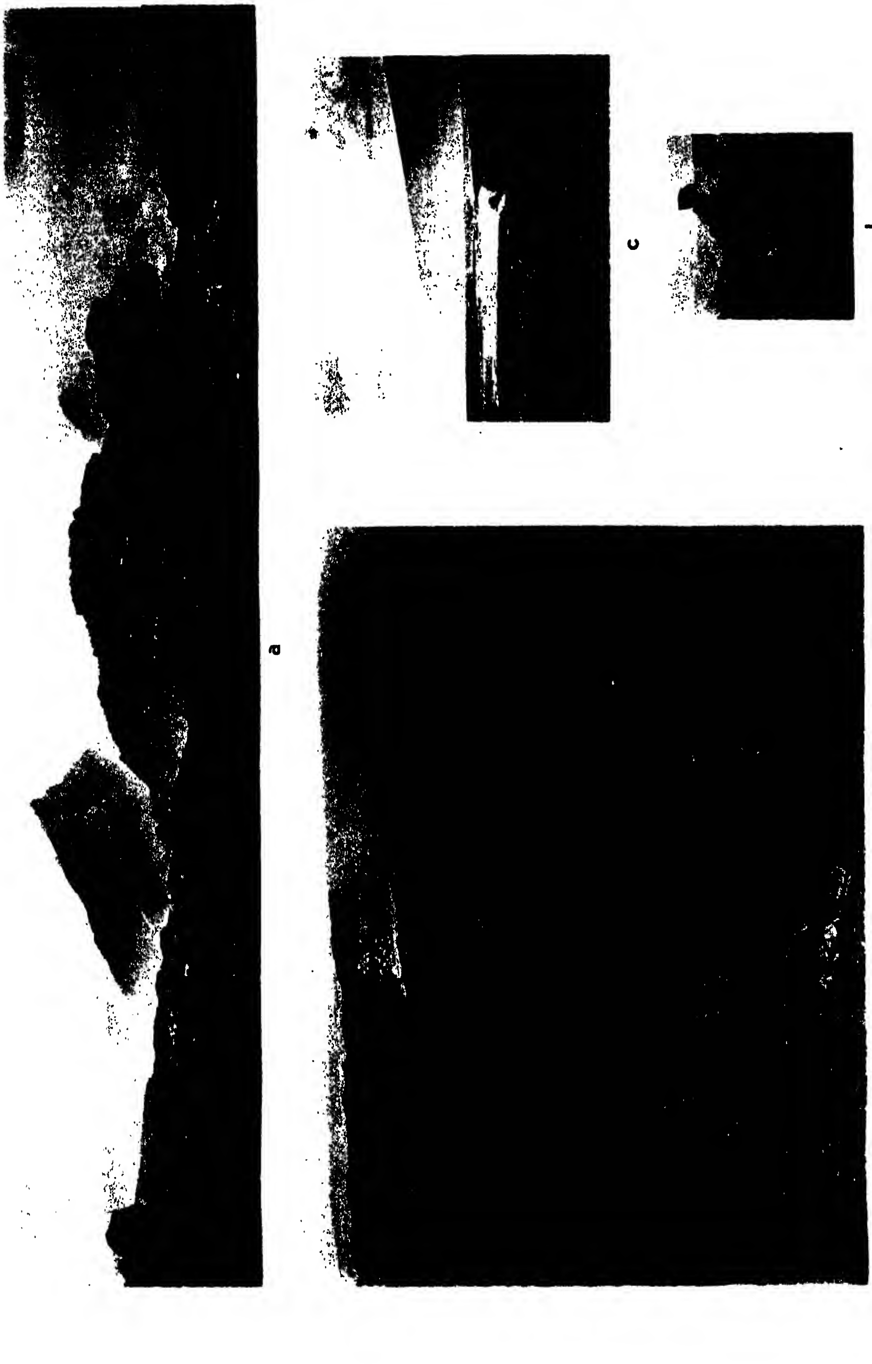
Plate 45.—DETAILS OF 1921–1922

a. Halemaumau September 26, 1921, showing recovery after the lowering period of the summer with a jumble of crags being lifted in the midst of lubricating liquid lava in much less volume. Looking southwest, depression 84 feet.

b. The southwest rift of Halemaumau May 25, 1922, depression 487 feet, showing rift cavern prolonged into dikes above and talus slopes below. Veneer on wall of recent high level and a portion of the pressure ridge on the left. Vertical scoring of epimagma occasioned by the scraping of lava lowering in the funnel shown along the wall-crack dike lower right side.

c. South bay of Kilauea Crater east of the gravel and ash spit looking southwest toward the distant slope of Mauna Loa, March 19, 1921. The smoking place on the cliff is where the fresh overflows from southwest of Halemaumau on Kilauea floor are filling the whole south end of the greater crater and spreading to this south bay so as to destroy the blue-green algae and solfataric deposits which characterized this ash section known as the Italian cliff. It was here that the rare primitive fern *Ophiuglossum* had been found. The overflows spread to the left through a gap in the low ash-wall of Kilauea and for a quarter-mile into Kau Desert.

d. Extraordinary hump in lava lake bottom of Halemaumau that rose suddenly just before date of photograph March 16, 1921. Depression 70 feet. The top of this mushroom tower had been a low flat islet in the lake, which as usual was 30 or 40 feet deep over an epimagma bottom. The epimagma was arched up suddenly as a function of the sudden rising of liquid lava that followed as shown in Plate 44 b.



DETAILS OF 1921–1922

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b

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KILAUEA FLOOR BEING FLOODED WITH LAVA APRIL 1919

Plate 46.—KILAUEA FLOOR BEING FLOODED WITH LAVA

a. Kilauea with Postal Rift flow, from Observatory, April 23, 1919, front opposite Uwekahuna.

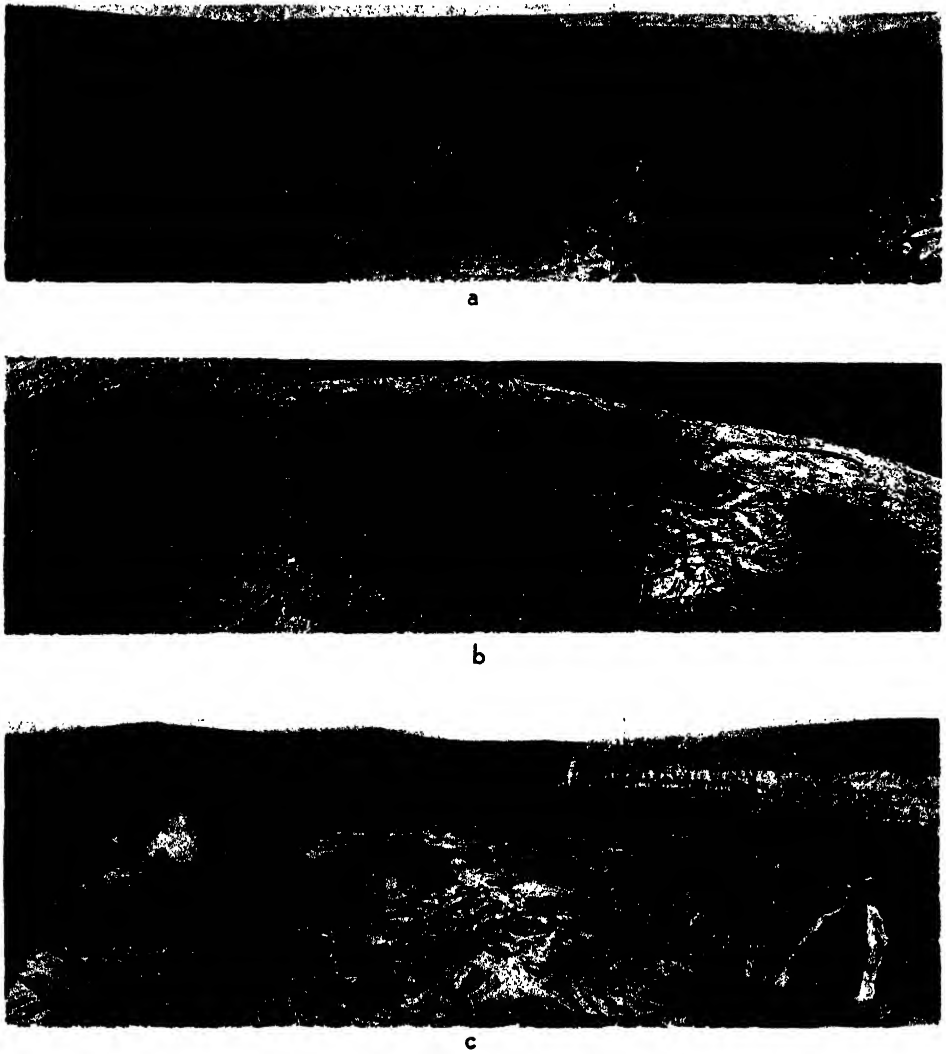
b. Same April 24, 1919, 11:30 a.m. front past Uwekahuna.

c. Same April 25, 1919, 11:45 a.m., front in north part of Kilauea floor. The white gypsum at base of cliff right was entirely buried under these outflows in 1919.

PLATE 47.—CHAIN OF CRATERS OUTFLOW 1923

Woodland west of Makaopuhi, Chain of Craters, burned by thin pahoehoe eruption up cracks August 1923, the rift being the belt of white stain lower right diagonal to center. Flow was from right to left, the ground humps are tree moulds. The white is yellow sulphur. Fountains left lava spatter clots in trees. Looking southwest, September, 1923.

CHAIN OF CRATERS OUTFLOW 1923



END OF CRAG DEVELOPMENT 1923-1924

PLATE 48.—END OF CRAG DEVELOPMENT

a. Halemaumau looking northeast May 1, 1923, depression 234 feet. Crag development mostly ended, large lake, flat shores and island, pit enlarged and broken southwest by the collapse of May 1922.

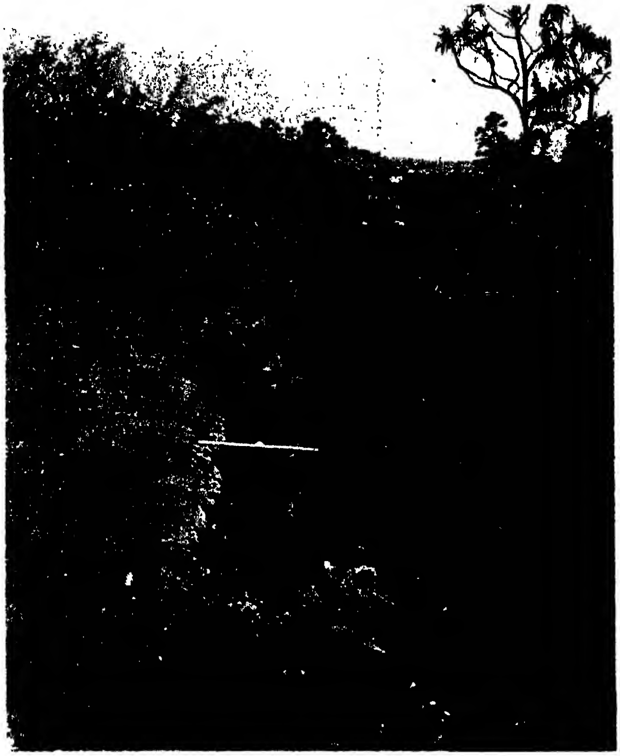
b. Halemaumau looking west November 12, 1923, depression 295 feet. Floor and pools, no development of crags.

c. Halemaumau looking southwest January 7, 1924, depression 200 feet. Outflow centers, pools, and flows, a suggestion of tabular crags, source at north cascading. Marked change since November by sinking and recovering.

PLATE 49.—PREMONITORY EVENTS AT KAPOHO

a. New crack open 2 feet at Kapoho, east point of Hawaii, on Kilauea east rift, April 1924, 30 miles from Kilauea Crater. The crisis of cracking and graben faulting that indicated submarine outflow preceding explosive eruption.

b. A surface water-supply pipe of plantation, indicating tensional pull northward to straighter course across graben, at Kapoho, when the country behind the camera sank about 3 meters. Looking toward south side of graben, which trends east with the rift belt. The pipe is drawn about 0.6 meter from its grass scar.



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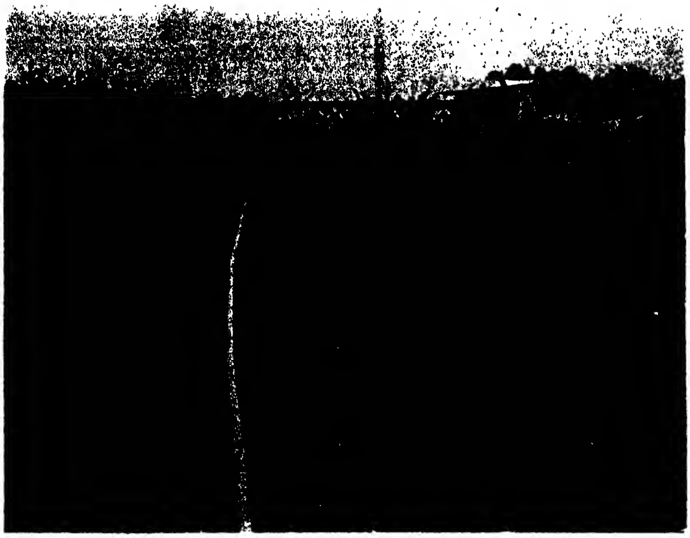

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PREMONITORY EVENTS AT KAPOHO APRIL 1924

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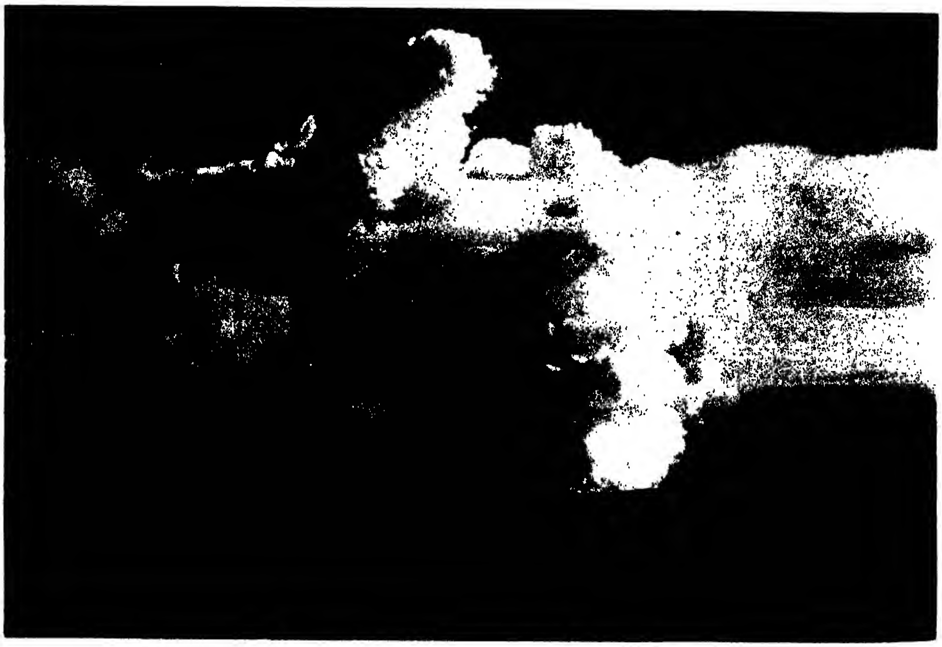

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EXPLOSIVE ERUPTION 1924

PLATE 50.—EXPLOSIVE ERUPTION

a. Halemaumau from Uwekahuna bluff, making cauliflower explosion 6000 feet high May 17, 1924, 12:30 p.m. Heavy barrage of boulders on Kilauea floor, vortical tongues and spirals, great engulfment and enlargement of pit, steam the upward ejecting agent, ejecta were avalanche debris. One of many rhythmical steam blasts of geyser type undermining Halemaumau in May 1924.

b. Halemaumau from Observatory June 1, 1924, after explosive activity ended. Pit enlarged in diameter from 1500 to 3000 feet, in depth from 300 to 1300 feet. Quiet pure steam rising from crevices in debris at bottom of pit.

Plate 51.—FEATURES AFTER EXPLOSIVE ERUPTION

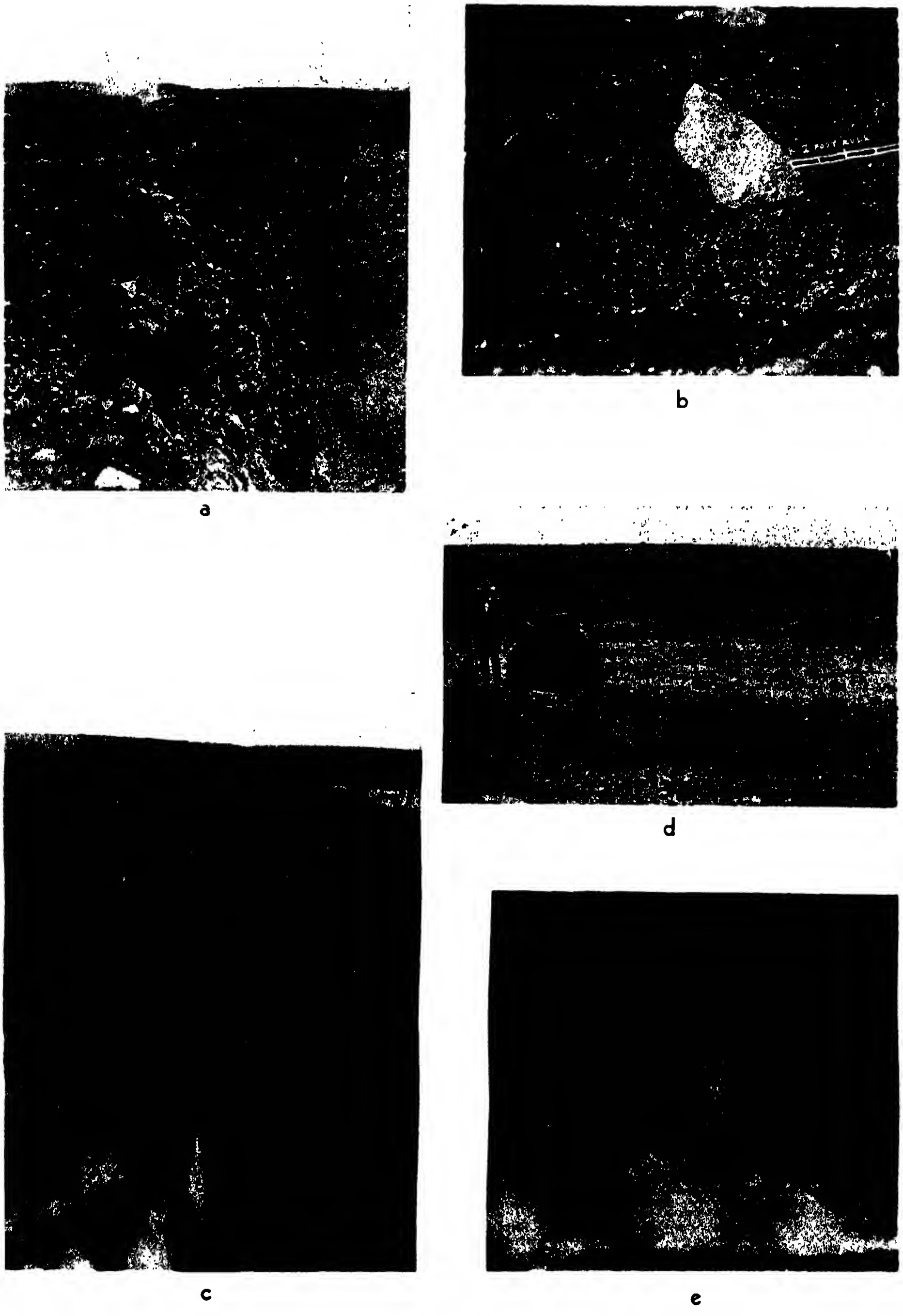
a. Halemaumau rim southeast June 1924, showing detached pinnacle and steam crack, depression to funnel of debris 1300 feet.

b. Boulder 2 to 3 feet in diameter which broke lava crust by force of impact on Kilauea floor May 23, 1924.

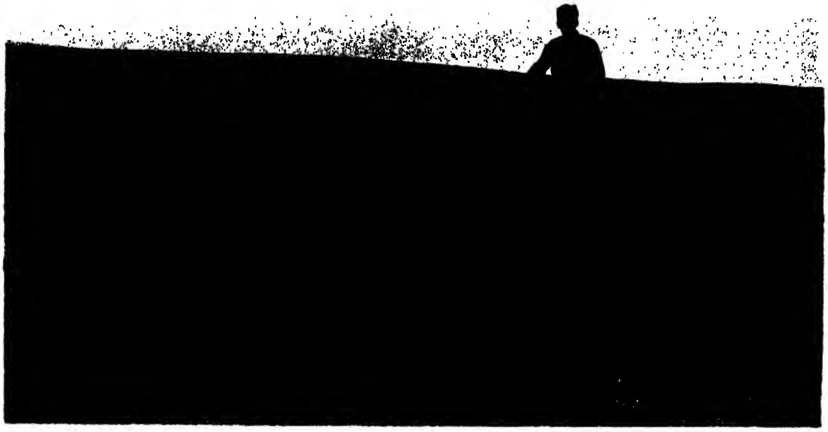
c. Southwest wall of Halemaumau after explosive eruption, looking south, June 1924, showing dikes of southwest rift and arcade openings, the upper one identical with that of Plate 45 b. These the tunnels through which Halemaumau communicated its lava by siphon to Kau Desert flow 1919–1920, and by well action to Red Solfatara December 1919 to March 1921.

d. Boulder of 1790 with its impact pit, looking south, 1 mile southeast of center of Kilauea Crater, indicating by line of trajectory and rebound that the center of 1790 explosion was farther north than that of 1924. (*See* Kirkpatrick and Jaggar, Part 3.)

e. Bottom taluses 1300 feet down steaming vigorously after explosive eruption, interior of Halemaumau on June 1, 1924, showing nodal areas free from steam.



FEATURES AFTER EXPLOSIVE ERUPTION 1924



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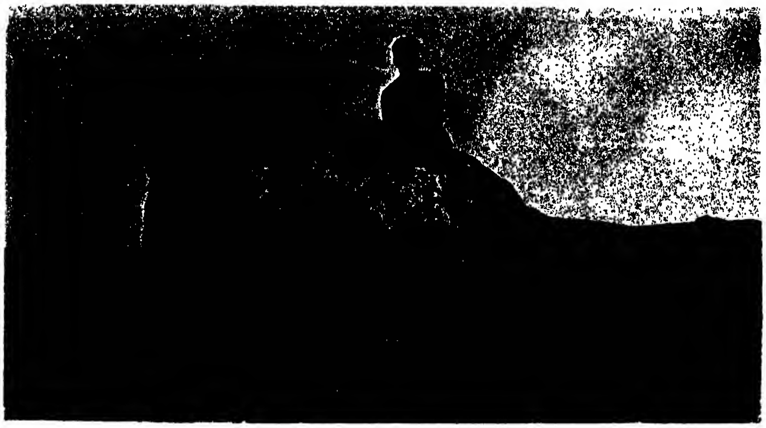

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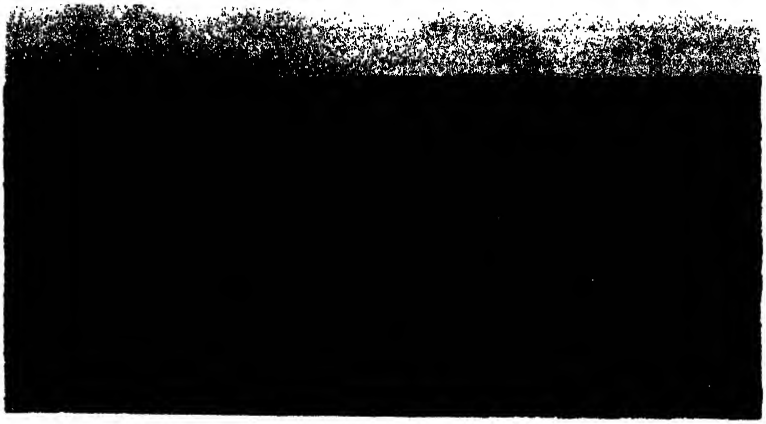

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ROCK FRAGMENTS 1924

PLATE 52.—ROCK FRAGMENTS

a. Eight-ton boulder 3/4 mile southeast from Halemaumau center, and its impact pit, showing line of trajectory to Halemaumau from boulder to camera. Rock broken by impact, a basalt fragment of avalanche debris. Fell in 1790 ash. *Compare* Plate 51 d. Photograph June 1, 1924, 1924 ejecta, looking southeast.

b. Ten-ton boulder of 1924 ejection 1800 feet southwest from Halemaumau center, fell on lava mantled with new ash. Photograph June 1, 1924, looking southwest.

c. Former road 2500 feet southeast from Halemaumau center, about where man was killed by rock barrage 11:15 a.m. May 18, 1924. The rock fragments are of diversified lithology—pieces of the pit wall, flows and intrusions, but all basaltic. Looking southeast, June 1, 1924.

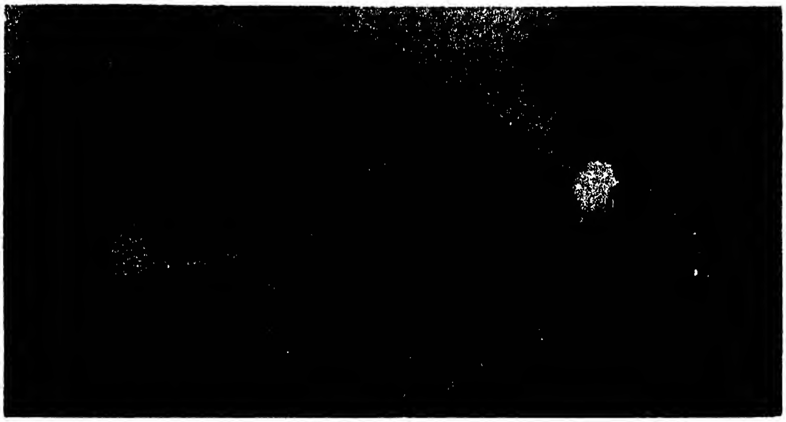
PLATE 53.—INFLOW OF 1927

a. Halemaumau pit looking northwest July 6, 1927, showing great white canoe sill of gabbroid rock representing U-shaped bottom of a former pit extending to the northeast. This sill was red hot and hard, making incandescent avalanches, in June 1924. Shows northwest and northeast talus cones, and fresh avalanche debris between them masking the lava floor of July 1924; all to be covered under lava of the eruption of the day following (July 7). Note steaming in only one place, compared with Plate 51 e. Second rim in background, is Uwekahuna bluff, with new National Park museum on its summit. At extreme left is a second subcircular section of an intrusive boss, which was also incandescent in June 1924. Depression 1240 feet.

b. Halemaumau July 7, 1927, 5 a.m., looking northwest, lava fountains building cones, in line in large pool.

c. Same July 15, 1927, showing after 8 days how completely the inflow had expended most of its volume on the first morning. Border rampart from which lake had shrunk was the conspicuous difference. Photos Wilson. Depression 1170 feet.

a



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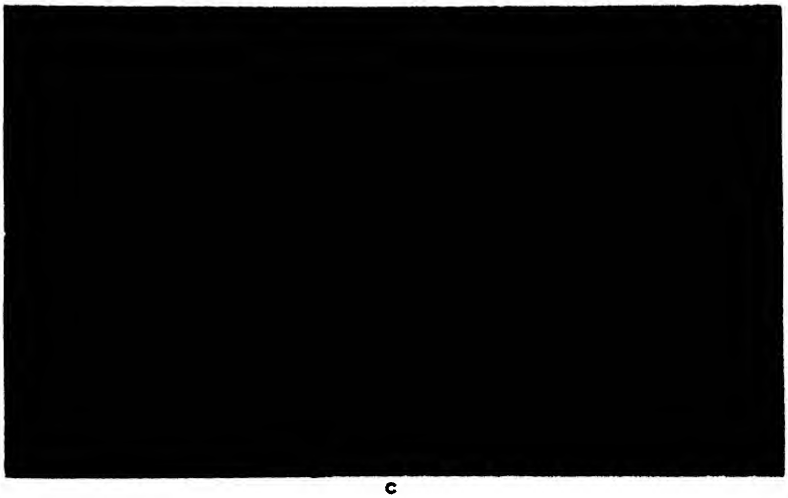

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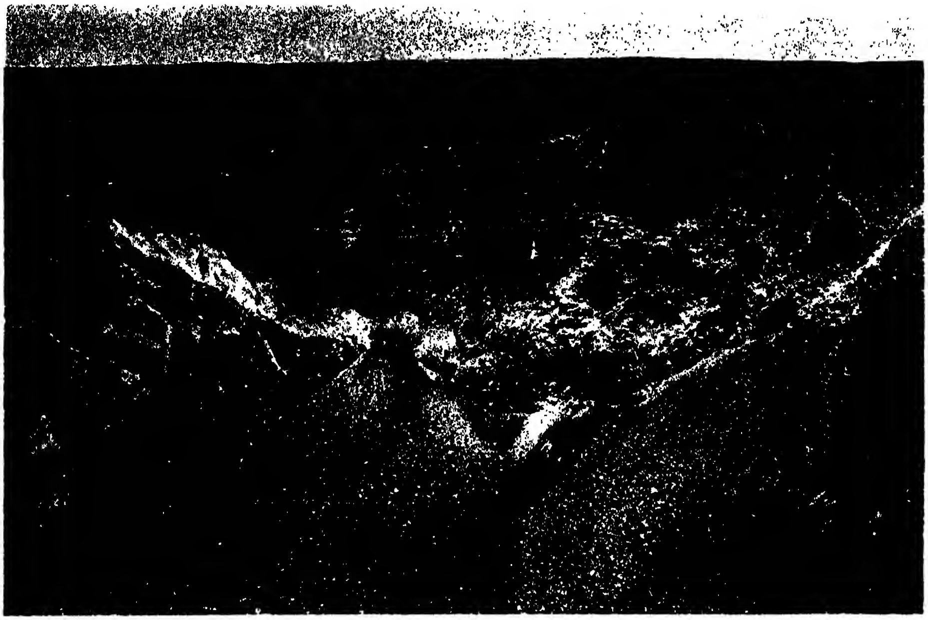

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THE HALEMAUMAU WALLS 1928

Plate 54.—HALEMAUMAU WALLS 1928

a. Halemaumau July 21, 1928, looking northeast showing distant Volcano House, the Canoe Sill, and the slender dikes of the southwest-northeast rift on the right and in the middle. The whitish band parallel to and above the left prow of the canoe is an old talus buried under horizontal basalt flows in cross section, revealing an ancient extension of U-shaped bottom of pit to the northeast. This heavy sill first seen in June 1924 was revealed red-hot making incandescent slides of hard fragments, after the engulfment of the explosive eruption. The buttresses right and left are upper extensions of free wall slabs with gulches of attrition behind them yielding the two taluses shown. The medial talus is under the rift belt. The thick faulted flow, upper right, is an old wall-crack heap of former pit rim, fractured by graben settling.

b. Halemaumau July 21, 1928, looking south-southeast showing 1927 cone and solidified lake at bottom and the dikes and tunnels of southwest rift belt in wall at right. Overlap of avalanches on 1927 floor is shown. Photos Wilson.

PLATE 55.—CONE SOURCES OF SOUTHWEST TALUS

a. Halemaumau July 28, 1929, looking west showing fountaining grotto pool building horseshoe half cone against west talus with condensing fume above. Dotted line shows lava level of 1932 that built similar half cone at about the same place but more to the left. Photo Maehara.

b. Halemaumau June 19, 1932, 10:00 a.m., looking west from airplane 11th Photo Section of Luke Field, U.S.A.C. Shows tendency to straight-sided polygon in pit formation. Typical buttress wall slab backed by gulches shown on the right. Circular boss in wall middle was red-hot intrusive after 1924 engulfment. Floor and cone of 1931 eruption similar to 1929. Marginal rim cracks are measured weekly by Observatory. Lower house left is seismograph cellar. Upper left, rift cracks of Kau Desert leading to rift dikes and tunnels of left Halemaumau wall. The near and far walls of Halemaumau, and the far wall of Kilauea are traces of the rift belt.

a

b

CONE SOURCES OF SOUTHWEST TALUS 1929, 1932

a

b

KILAUEA AND HALEMAUMAU 1934

PLATE 56.—AIRPLANE VIEWS OF KILAUEA CRATER

a. Southwest margin of Kilauea September 6, 1934, 5:00 p.m., from airplane 11th Photo Section, U.S.A.C. Looking west at Mauna Loa slope, Halemaumau active on right. Rift cracks from Kilauea to Kau Desert right to left. Desert wash in foreground. Slide making dust on cliff due to working of rift belt first evening of Halemaumau eruption.

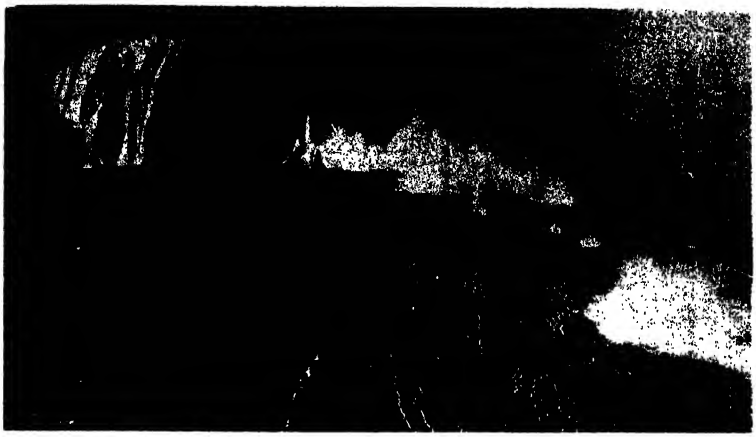
b. Halemaumau from same airplane about 5:00 p.m., September 6, 1934, looking southeast showing fume from pit and rift belt, gashes of Uwekahuna fault cliffs in foreground, distant cliffs of Kilauea graben near horizon.

PLATE 57.—STAGES OF 1934 INFLOW

a. Halemaumau September 6, 1934, 5:00 a.m., looking northwest from rim of pit. Shows half ring of wall-crack fountains from lower right to upper left that followed lifting plug of 1931 to lifted wall slab upper left whence came 25 ribbon cascades from 300 feet above pool. Cascades left and right of wall slab, each with fountain source, these fountains extending into line of big fountains at pool margin. Offset is a second line extending to the right marking edge of submerged 1931 cake. Bright-line pattern of crusts and radiating waves in heavy slag pool from fountain centers. Photo Maehara.

b. Halemaumau September 7, 1934, 8:30 a.m., looking west from airplane 11th Photo Section, Luke Field, U.S.A.C. Cascades solidified, cascade fountain source fuming, 1931 cone crescent shown at left, wall slab well shown, streaming from fountains like leaf delta, left margin of pool congealing inwards toward swelling epimagma around fountains.

c. Halemaumau September 16, 1934, looking north showing shrunken lake at north end of floor, fountains of pyromagma forming cones in epimagma, lake now at top of a heap within its own ramparts. At end of eruption this heap flattened out by marginal outflow. Photo Maehara.



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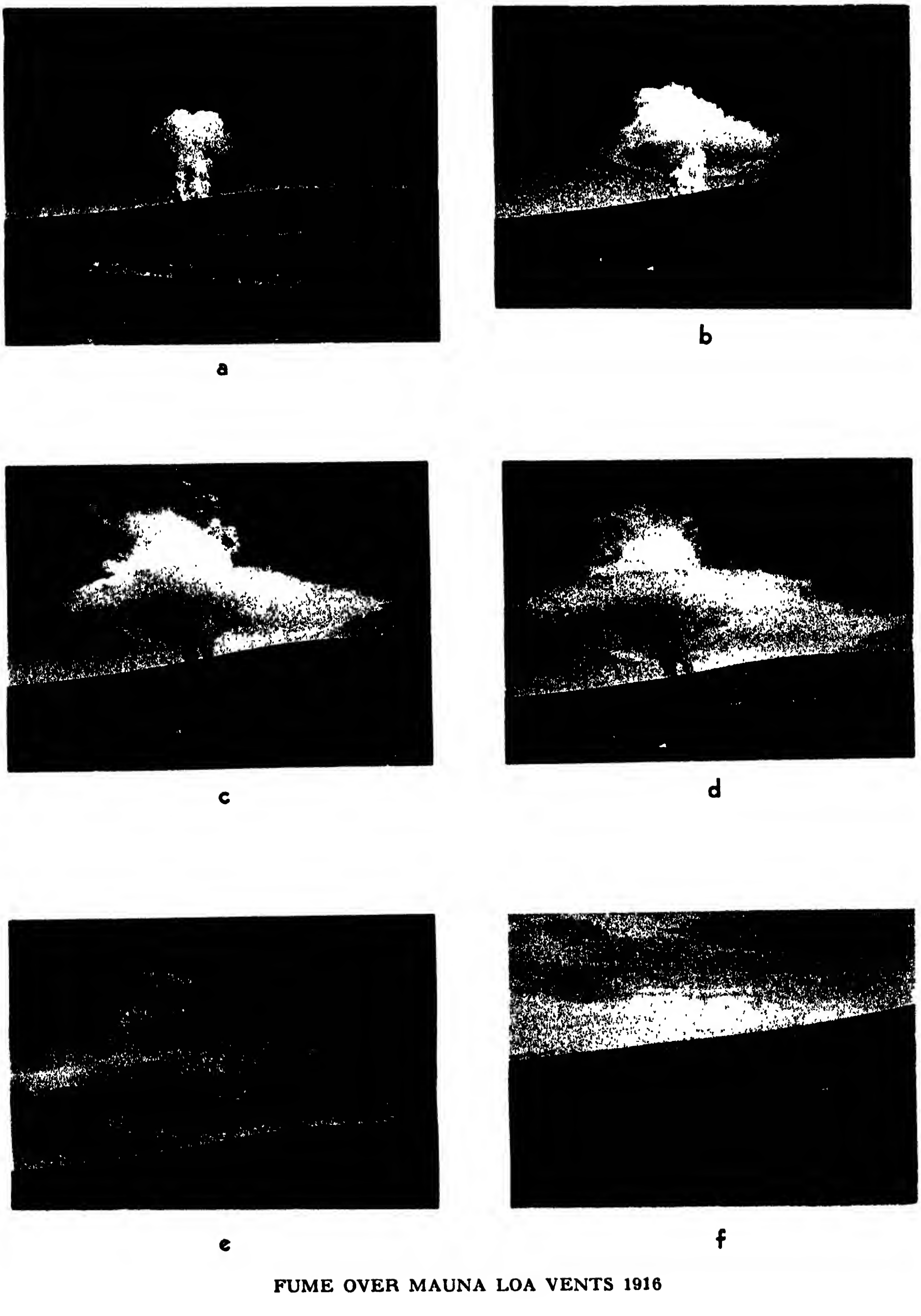

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FUME OVER MAUNA LOA VENTS 1916

PLATE 58.—FUME OVER MAUNA LOA VENTS 1916

a. Mauna Loa outbreak May 19, 1916, from Kilauea Observatory 7:50 a.m., two columns rising.

b. Same at 8:00 a.m., elongated belt of fume along rift, elliptical cumulus above.

c. 8:30 a.m., contraction to two fume columns, enlargement of cumulus.

d. 8:45 a.m., decline of upper fume column expansion of cumulus to funnel shape. Fume jet above punctures cumulus.

e. 9:05 a.m., only lower fume column persists, cumulus and upper fume diffusing.

f. May 22, 1916, 8:30 a.m., new fume jets and cumulus in Kahuku several miles down rift from first outbreak, source of outflow. Photos Wood.

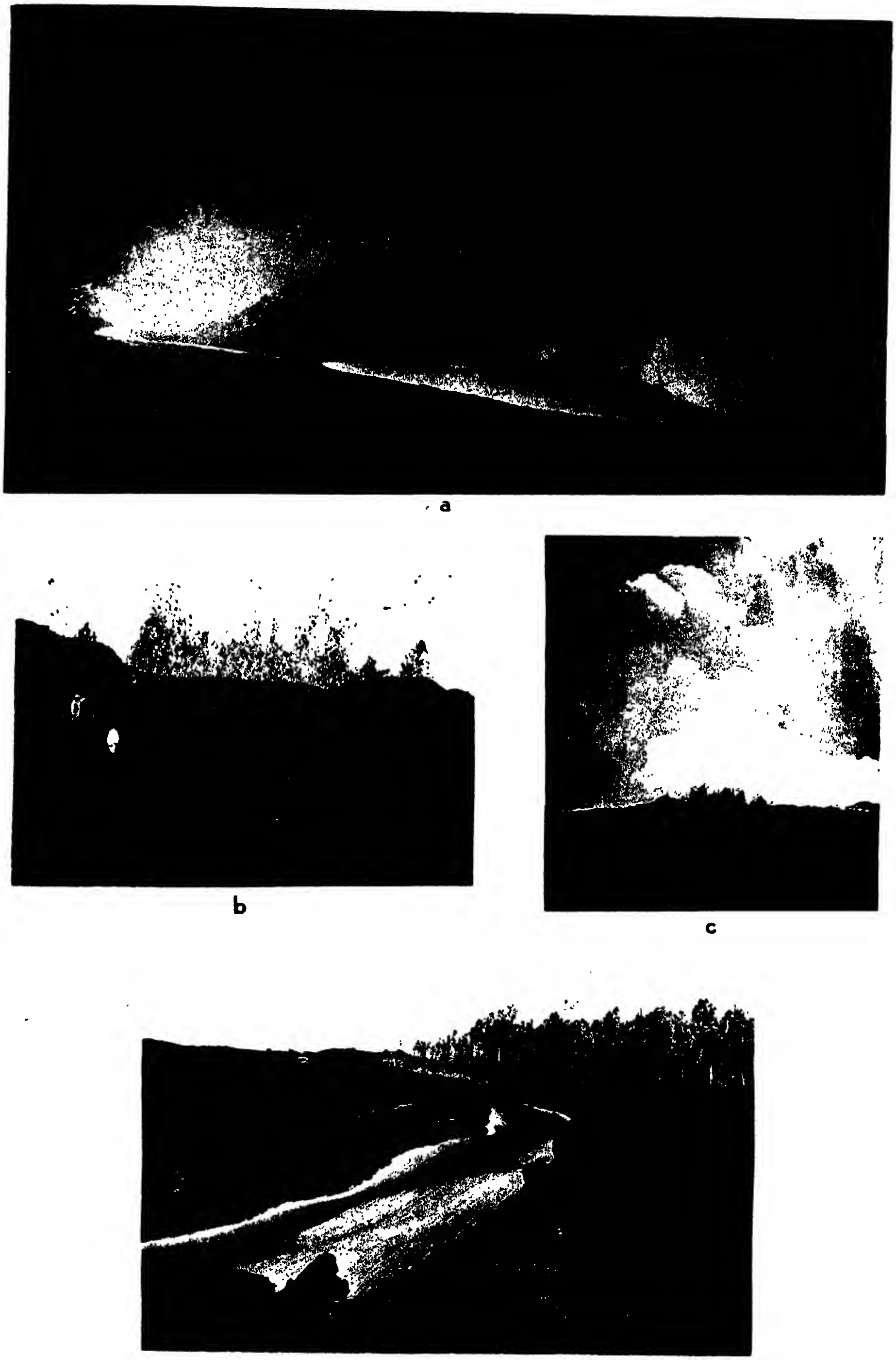
Plate 59.—MAUNA LOA SOUTHWEST FLOWS 1919

a. Mauna Loa eruption October 25, 1919, looking south at night showing six bright-orange jets from lava fountains building cones along rift. Big fountain and cone in foreground giving vent to Alika flow pouring west. Region about 8000 feet elevation, southwest rift of Mauna Loa, mountain slope about Puu Keokeo.

b. Mauna Loa October 1, 1919, detail of blood-red larger fountains in daylight looking west across rift heapings, same region as (a).

c. Same date and place as (b), but farther away, showing multiple accumulation of fountaining crack and the high reddish-brown fume clouds which have bluish-green flames at their base, above the fountains.

d. Mauna Loa southwest at South Kona road October 6, 1919, looking northeast, showing torrent of molten aa lava travelling 11 miles an hour within overflow fields of earlier consolidation of the same eruption. Glowing border grottoes of epimagma, bright yellow at night. Torrent carries rafts down the middle on its standing waves which sweep by the observer silently, with only slight swishing noise. Field oppressive with foundry smell, red hot down cracks. Torrent dull red in daylight, orange at night, shows its aa crystallinity, only uncongealing.



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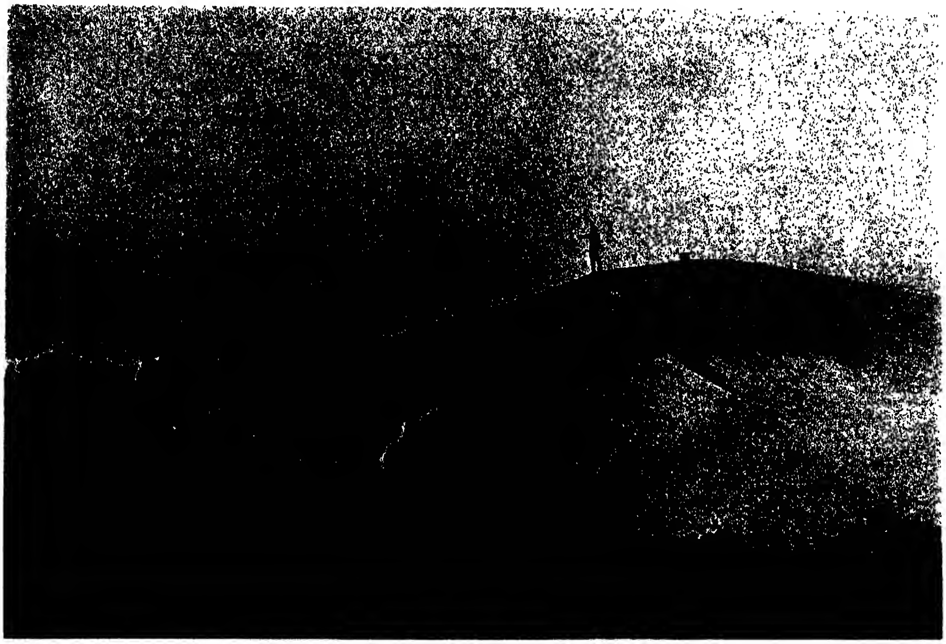
MAUNA LOA SOUTHWEST FLOWS 1919



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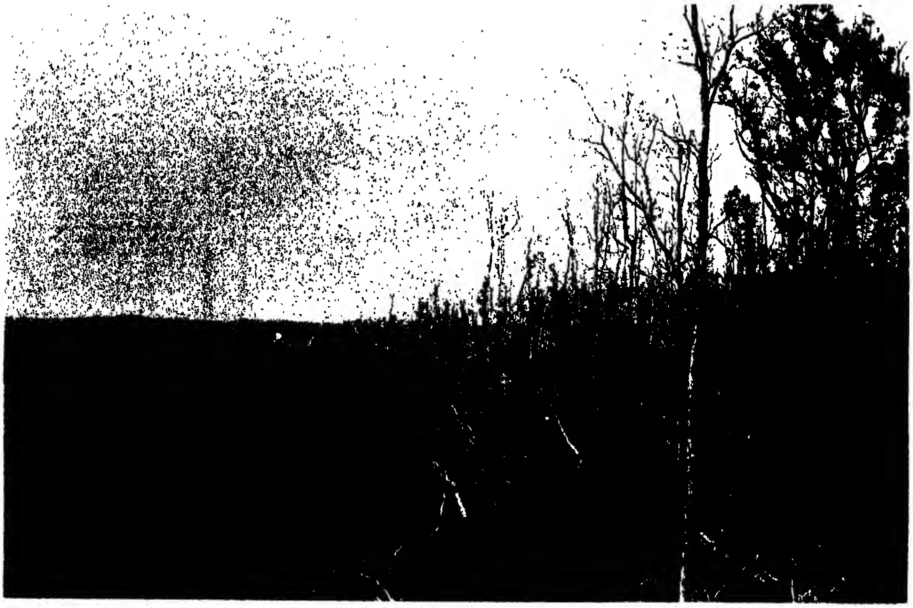


b

DETAIL OF MAUNA LOA FLOW 1919

PLATE 60.—DETAIL OF MAUNA LOA FLOW 1919

a. Mauna Loa flow at Alika shore, South Kona October 28, 1919, looking west. Shows sand cone flung up by steam explosions where aa flow entered the sea over a low cliff, the cascade of molten aa in salt water making a craterlet in sand and gravel around the torrent. Sand slope coated with crystalline sea salts. Craterlet is on the right, fresh lava in foreground.

b. Alika flow of 1919 near road in South Kona looking west showing fallen ohia trees at north edge of aa flow. Inward fall probably due to undermining by fire on flow side of each tree, and inward drag of contracting flow on burning tree trunks surrounded by the lava. Photo Baker.

PLATE 61.—SOUTHWEST MAUNA LOA FLOW 1926

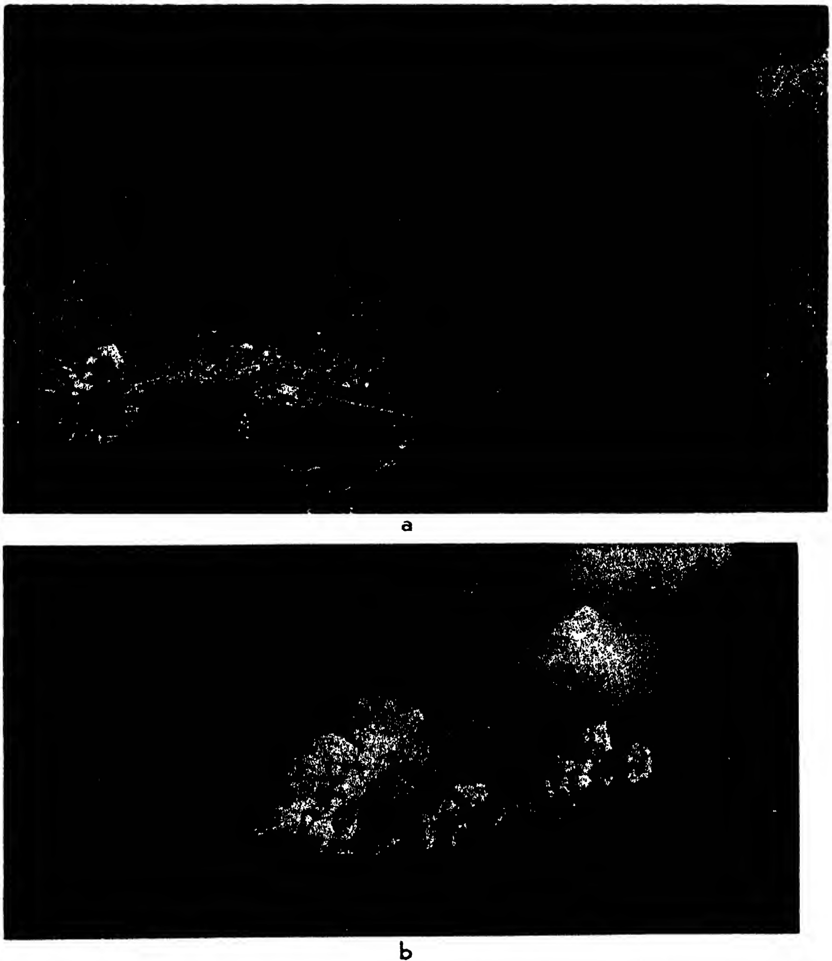
a. Mauna Loa aa flow April 18, 1926, 5:16 a.m., Hoopuloa Village being burned and buried looking south. View from the wharf shown in Plate 62 a and b. On the right Mary Ai's house shown on the right of the harbor in Plate 62 a.

b. Hoopuloa flow at Hoopuloa April 26, 1926, showing large sprouts of aa making cliff on side of flow, looking southeast from north remnant of village. Photos Tai Sing Loo.

a

b

SOUTHWEST MAUNA LOA FLOW 1926



SOUTHWEST MAUNA LOA FLOW IN OCEAN 1926

PLATE 62.—SOUTHWEST MAUNA LOA FLOW IN OCEAN, 1926

a. Mauna Loa aa flow April 17, 1926, from airplane looking east at Hoopuloa harbor and footslope of Mauna Loa in South Kona. From elevation 2000 feet, 4:07 p.m. by 11th Photo Section U.S.A.C. Shore road right leads to Miilolii. Wharf is structure with black roof. Automobiles on the left. Massive stream within flow delta quite different from narrow torrent of 1919.

b. Photo by same air force April 18, 1926, 7:18 a.m. from less elevation looking southeast showing steam development when sluggish lava entered ocean, no individual sand hills, wharf being destroyed, ocean simmering in front of flow, light-green turbid line within margin of simmering area, thousands of fish killed. No loss of human life, people retreated along road in both directions.

c. Terminus of Hoopuloa flow in sea April 26, 1926, looking southwest, old sea-worn boulders in foreground. Sand at point beginnings of a bar that shut off this cove during the following year.

PLATE 63.—AIRPLANE VIEWS MAUNA LOA RIFT BELT

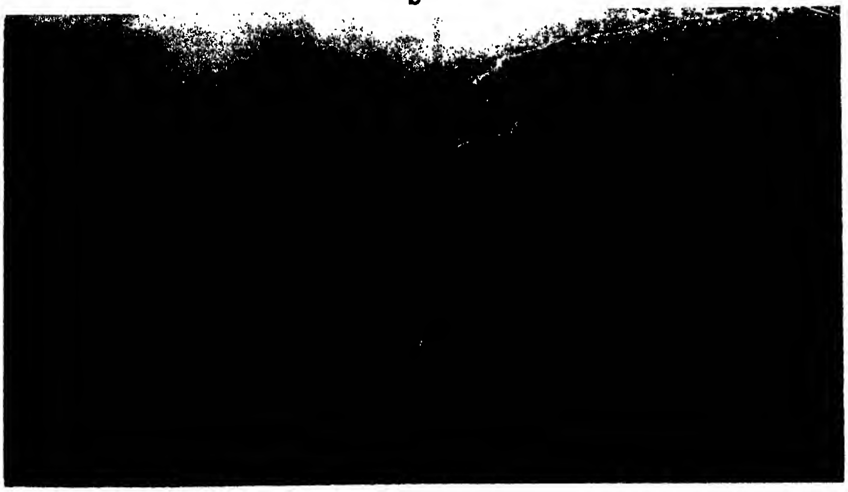
a. Mauna Loa flow sources from airplane April 18, 1926, 6:35 a.m. showing upper steaming part of new rift crack looking west, ground at about 9000 feet elevation.

b. Same rift belt looking north, ground at about 8000 feet elevation, showing a mile of active cones April 18, 1926, 7:20 a.m., and cones along old portions of the rift. Exhibits well the characteristics of rift belt and its true fissure eruptions. Left foreground glowing torrent flowing along rift crack and cascading into a well. Fuming cones are basaltic pumice 50 to 75 feet high. The line of Alika cone sources of 1919 hidden by fume in background. Whole rift belt is 2 to 3 miles wide.

c. Hoopuloa flow April 18, 1926, 6:53 a.m., looking northeast at South Kona slope about 7000 feet elevation, showing same lava torrents of pahoehoe as lower left of (b), entering upper right and making transition to aa floods of the branches already congealed. Overlap of distributing pahoehoe river on aa fields is well shown, all the torrent lower left being potential aa owing to the process of stirring and crystallization. Old light-colored pahoehoe with line of tunnels left middle, old aa channel lower right. Photos 11th Photo Section U.S.A.C.

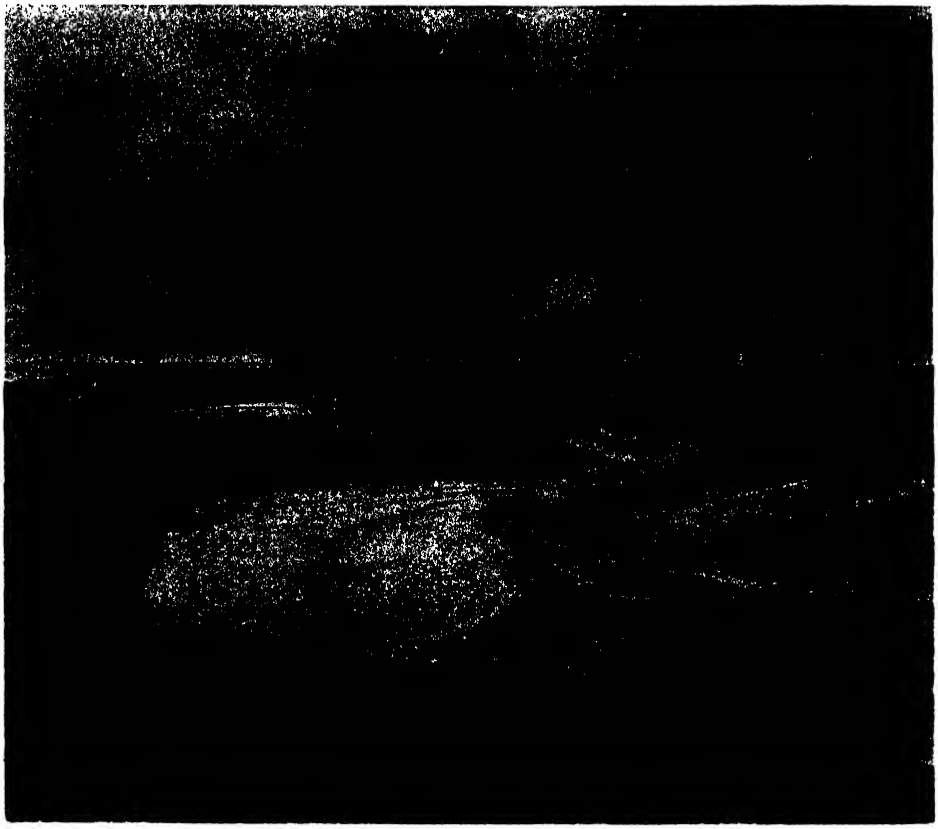
a

b



c

a



b

SUMMIT ERUPTION MAUNA LOA 1933

PLATE 64.—SUMMIT ERUPTION MAUNA LOA 1933

a. Mokuaweoweo Crater from airplane looking west June 25, 1929. Plane at elevation 13,675 feet. Shows crater condition prior to (b). West wall 652 feet high, summit 13,680 feet. Foreground the east summit plateau where Wilkes camped in 1840. South lunate platform on left. 1903 cones near side of floor, 1914 cone and basin left side of floor. Photo 11th Photo Section U.S.A.C.

b. Mokuaweoweo Crater from airplane at elevation 14,250 feet, looking southwest toward distant Kona shore, December 2, 1933, the day of outbreak. Echelon fractures vomiting lava, extending from 1914 cone on the right to southwest wall of crater on the left and through the wall to the upland beyond. Gushing there was close to flow source of 1851. Trend of fractures S 27° W. Cascade into south pit from wall and from wall-crack overflows of south lunate platform. 1914 bowl filling east side of Mokuaweoweo with bounding cliff and rim cracks shown in foreground. Color of fume absinthe red. (*See* Volcano Letter No. 439.) Photo Fleet Air Base, Pearl Harbor, U.S.N.

PLATE 65.—NORTHERN OUTBREAK OF MAUNA LOA 1935

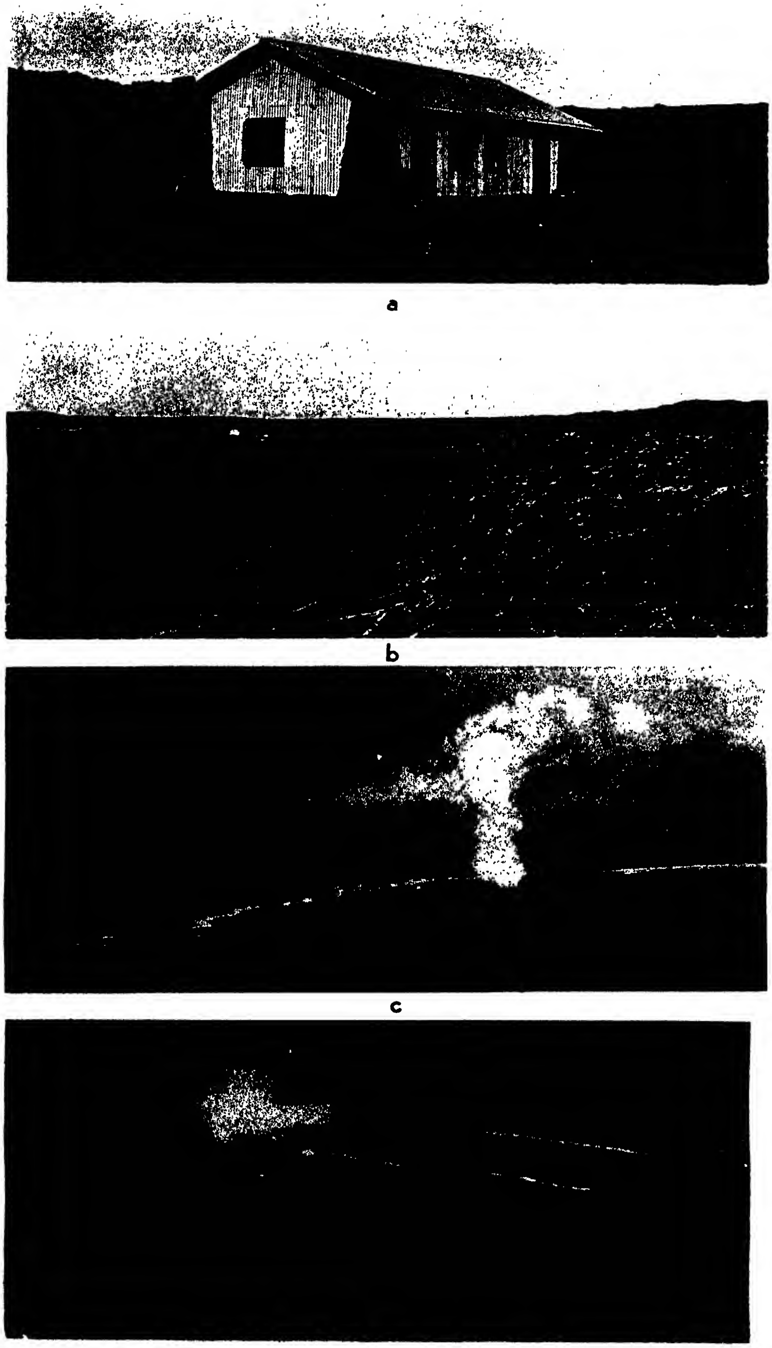
a. Northeast slope of Mauna Loa looking southwest with snowy Mokuaweoweo Crater in background, airplane photograph November 22, 1935, first day of outbreak. Flank eruption from north end of Mokuaweoweo downward, sequent on crater eruption of 1933. Rupture of west side of rift belt about 12,000 feet elevation. Fume of effervescence upper center, ground water vapor lower right. Fracture through old cone with lava torrent flowing along fracture and forking around cone; cascade into crack below cone. Fume jet middle right from lava cascade into old pit. These are the rushing pahoehoe flows of pumiceous basalt stirred immediately into rough aa just below. Old transitions from pahoehoe to aa along ancient flow channel on the left, where lies crest of divide. Photo Fleet Air Base, Pearl Harbor, U.S.N.

b. North slope of Mauna Loa looking south across same flow sources as (a), from airplane, December 27, 1935, showing rift belt across a quarter of the photograph from lower left to upper right, and extreme straightness of 1935 crack. Fuming activity concentrated in two wells with built-up ridge and cones. Main cone at elevation about 12,000 feet, outflow in progress 3000 feet down the mountain, not shown, outside of foreground. Pahoehoe flows and stream channels covering most of the earlier aa illustrates how source lava is mostly pahoehoe, overlapping aa farther down as shown by Plate 63 c. No flowing in progress in this picture. Photo Fleet Air Base, Pearl Harbor, U.S.N.

a

b

NORTHERN OUTBREAK OF MAUNA LOA 1935



DETAIL OF MAUNA LOA ERUPTION 1935

PLATE 66.—DETAIL OF MAUNA LOA ERUPTION 1935

a. Summit resthouse of National Park, Mauna Loa, June 1935, north side of north bay of Mokuaweoweo looking northeast.

b. North bay of Mokuaweoweo looking west-northwest from resthouse January 1936. Shows thin new fill of pahoehoe lava from the beginning of 1935 eruption at uppermost end of rift.

c. Outbreak along northeast rift of Mauna Loa as seen from Waimea looking south-southeast evening of November 22, 1935. Same rift crack in eruption as Plate 65a seen from a greater distance, showing the old cones of the rift belt in mountain profile left, the fountaining crack from 11,500 to 12,000 feet, and the north-flowing aa flows bounded on the east by the 1843 flow.

d. Mauna Loa, its snowy crest, and profile of northeast rift November 24, 1935, from south slope of Mauna Kea near Humuula looking south. Shows fume column of upper fountain source blown to southwest. Long flow is the aa torrent of first 2 days. Small lower gush left of middle is the lower Humuula flow source at elevation 8900 feet.

PLATE 67.—AA AND PAHOEHOE SEQUENCE

a. Mauna Loa from summit of Mauna Kea looking south-southwest August 1925, showing summit profile of Mokuaweoweo Crater. Flows mostly from northeast rift belt. Extreme left 1899 flow with light medial belt. Third from left probably flow of November 1880. Fourth flow, very wide, pahoehoe above aa is 1843 flow. The 1935 November flows came down the light-colored old pahoehoe to the right of 1843. The later Humuula flow of December came out in the light-colored embayment to the left of 1843. Photo Emerson.

b. Mauna Loa looking south from foothills of Mauna Kea west of Humuula December 11, 1935. Northeast rift cones in profile. November aa flows right of middle. Black flow in foreground right is 1843 aa overlapped in background by 1843 pahoehoe. New aa flows of lower Humuula vent make the dark belt fuming up middle of picture.

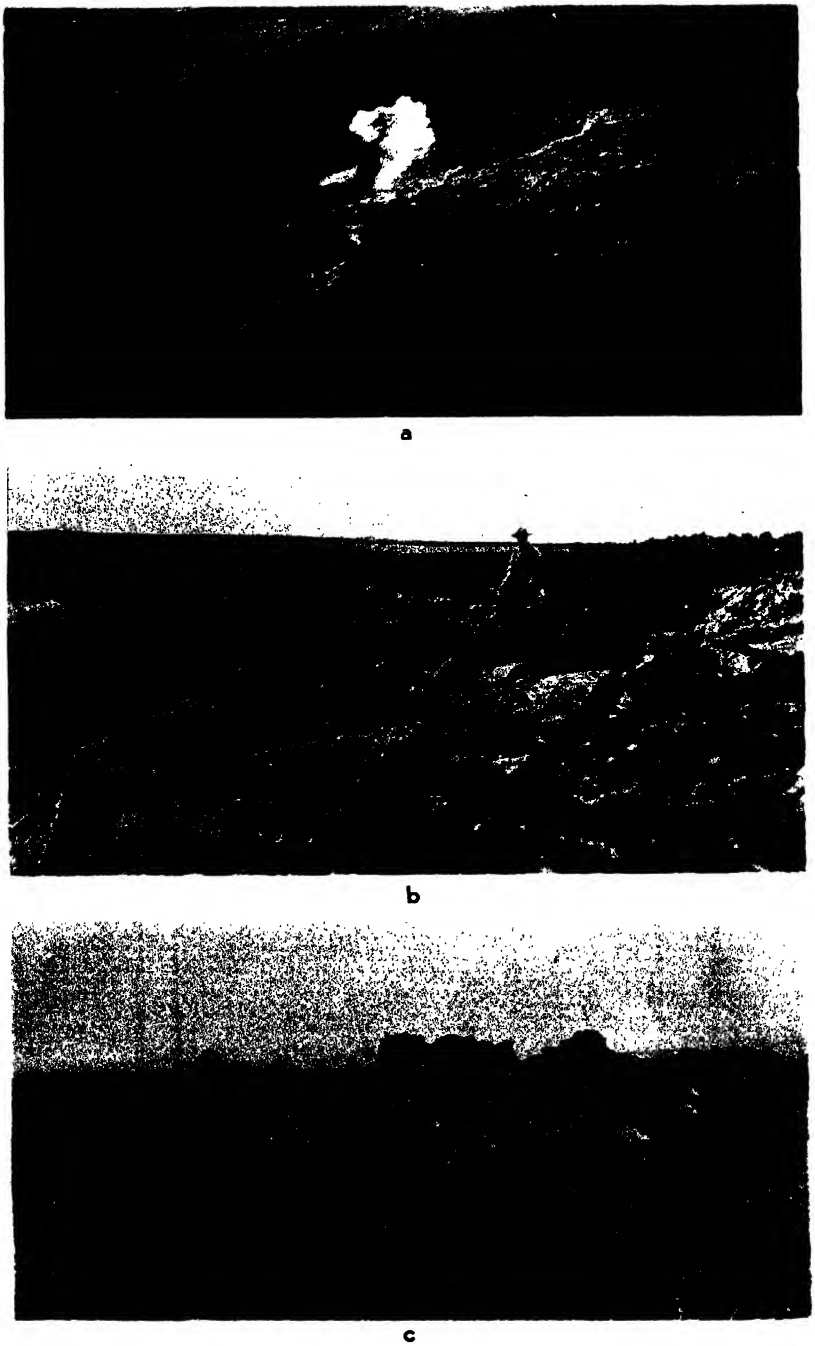
c. Same scene December 21, 1935, showing the gleaming pahoehoe of 1935, adjusted to a vitreous upper skin, which has followed down the mountain, on the right-hand side of the 1935 aa in the photograph. It bends to the left or east between 1843 aa and 1935 aa and makes a lake of pahoehoe lava in Humuula saddle against Puu Huluhulu, the wooded hill on the left. Photograph demonstrates striking resemblance of 1935 flow to 1843 flow in position, size, and sequence of pahoehoe after aa. The day after this picture was taken the flood of lava escaped to the east toward Hilo on the extreme left.

a

b

c

AA AND PAHOEHOE SEQUENCE 1935



BOMBING OF MAUNA LOA 1935

PLATE 68.—BOMBING OF MAUNA LOA 1935

a. North slope of Mauna Loa December 27, 1935, early afternoon, looking southeast, showing source slag heap and pahoehoe channel of 1935 lower flow at about elevation 8000 feet. Bomb exploding at bend of the channel as dropped from Army airplane. The bombs opened the tunnels and cooled the lava. Taken by 11th Photo Section, U.S.A.C.

b. Bomb crater March 5, 1936, with upturned rim slabs along tunnel channel shown by (a).

c. Rim slabs upturned around a bomb crater March 5, 1936, showing in foreground the gushing overflows of pahoehoe that were released by the bomb explosion.

PLATE 69.—FLOW DEVELOPMENTS MAUNA LOA-MAUNA KEA SADDLE, 1935

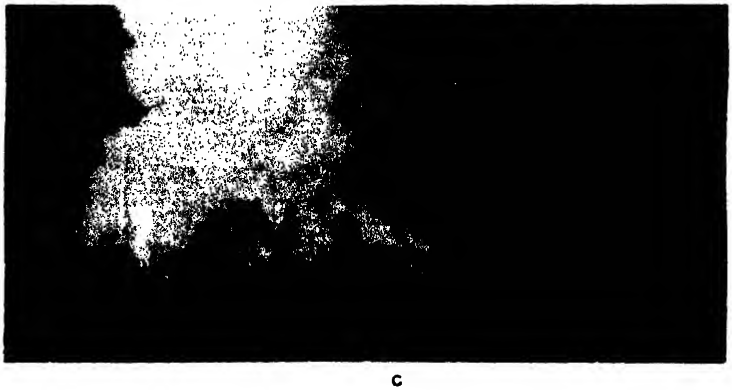
a. South slope of Mauna Kea looking west-northwest from airplane August 6, 1935, showing road and Humuula sheep station in foreground before 1935 eruption. Saddle between Mauna Kea and Mauna Loa lower left. Photo 11th Photo Section from elevation 11,000 feet, U.S.A.C.

b. Some of the same hills shown on the left of (a). Looking north about December 26, 1935, showing in foreground creeping tongue of pahoehoe lava lake, burning the grass at Mauna Kea edge of the saddle that separates that mountain from Mauna Loa. In the grassy stretch there were many underground explosions close to the lava front in old caverns where water gas collected from burning sod.

c. Advancing front of aa flow December 27, 1935, 3:00 p.m., in Puu Oo ranch about 5 miles east of Humuula. Flow escaping from pahoehoe tunnels at Puu Huluhulu turn to aa down the steeper slope toward Hilo. Here it is seen burning the forest and making lateral branches. Taken from elevation 10,000 feet by 11th Photo Section U.S.A.C.

a

b



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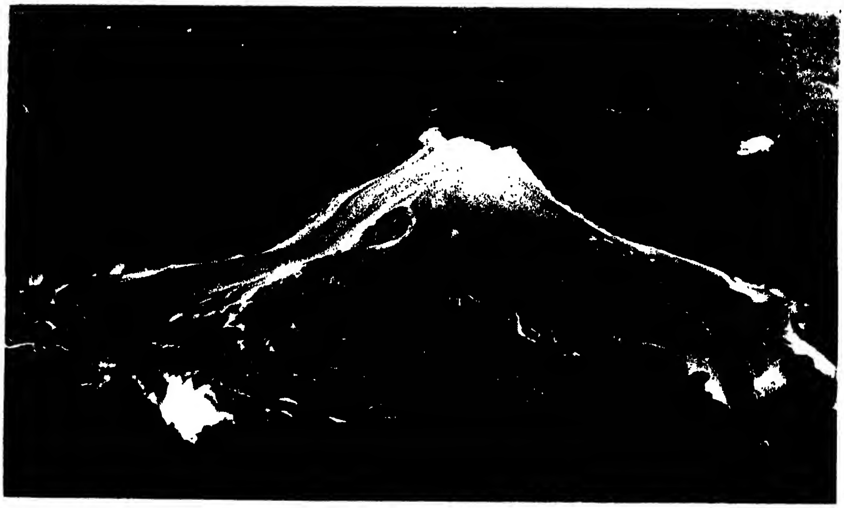
FLOW DEVELOPMENTS MAUNA LOA-MAUNA KEA SADDLE, 1935

a



b

c

DETAILS OF PAHOEHOE MAUNA LOA 1935

PLATE 70.—DETAILS OF PAHOEHOE MAUNA LOA 1935

a. Pahoehoe front of 1935 pushing eastward over the rough aa surface of 1843. Looking west December 10, 1935, in middle region of photograph Plate 67 c.

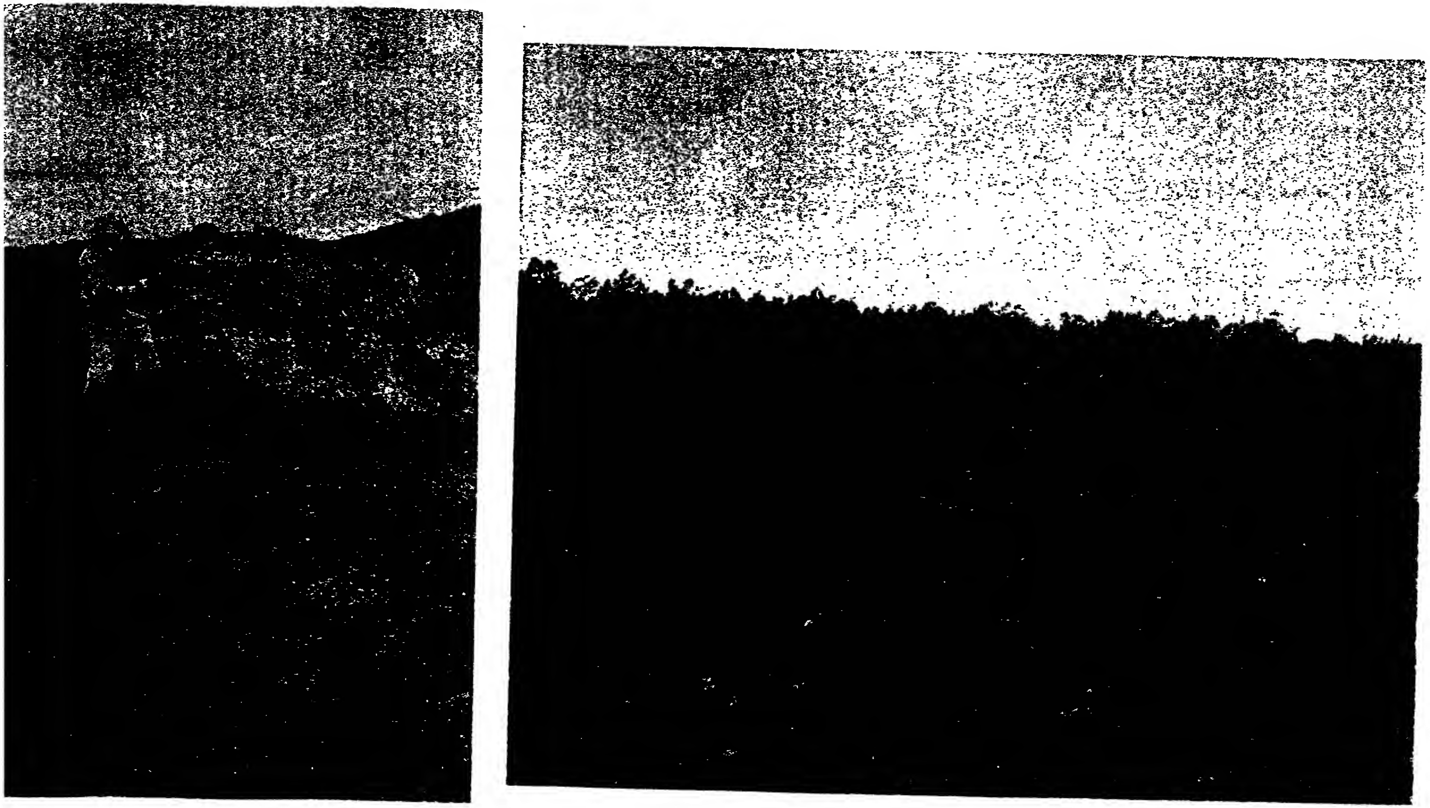
b. Pahoehoe of the advancing lava December 21, 1935, cascading into hollows of old aa near Humuula.

c. Same vicinity and date as (b), showing pahoehoe advancing into the grass and burning trees near Humuula.

PLATE 71.—AA LAVA TYPES MAUNA LOA

a. Alika lava flow in South Kona of October 1919 showing aa texture and one of the rafts of concretionary pahoehoe brought down the inner channel of flow and stranded on the bank. Photographed in May 1920.

b. The bouldery aa that covered Hoopuloa village April 26, 1926, showing difference of texture from the aa of (a).

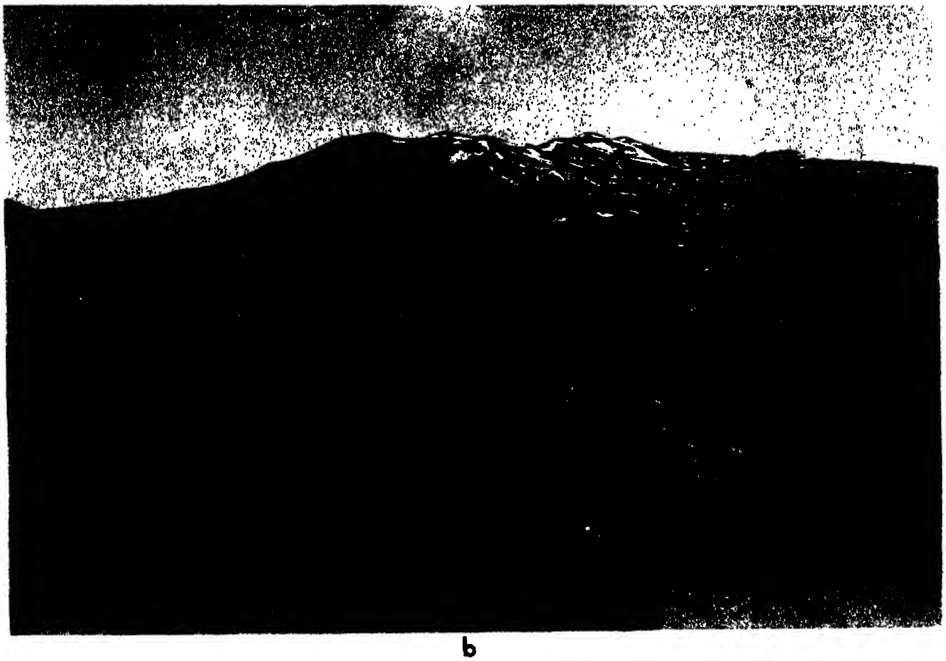


a

b

AA LAVA TYPES MAUNA LOA 1919, 1926

a



b

CRATERAL REGION OF MAUNA KEA

Plate 72.—CRATERAL REGION OF MAUNA KEA

a. So-called cinder cones of Mauna Kea from the air looking west showing circularity of cone and funnel made by the viscous basalt in condition capable of producing almond bombs. Here the horseshoe or crescent from which fountaining lava flowed is absent. Pahochoe of Mauna Kea shown in background, and flows are by no means lacking on this mountain. Photo Inter-Island Airways 1933.

b. Summit region of Mauna Kea May 12, 1933, showing glacial moraines between the volcanic cones. This is the crater region marked by a plateau rim but buried under viscous accumulations and many cones. Photo Fleet Air Base, Pearl Harbor, U.S.N.

PLATE 73.—SURFACE PATTERNS OF KILAUEA LAVA

a. Spiracle or spatter cone built about 1894 south floor of Kilauea Crater photographed July 14, 1914.

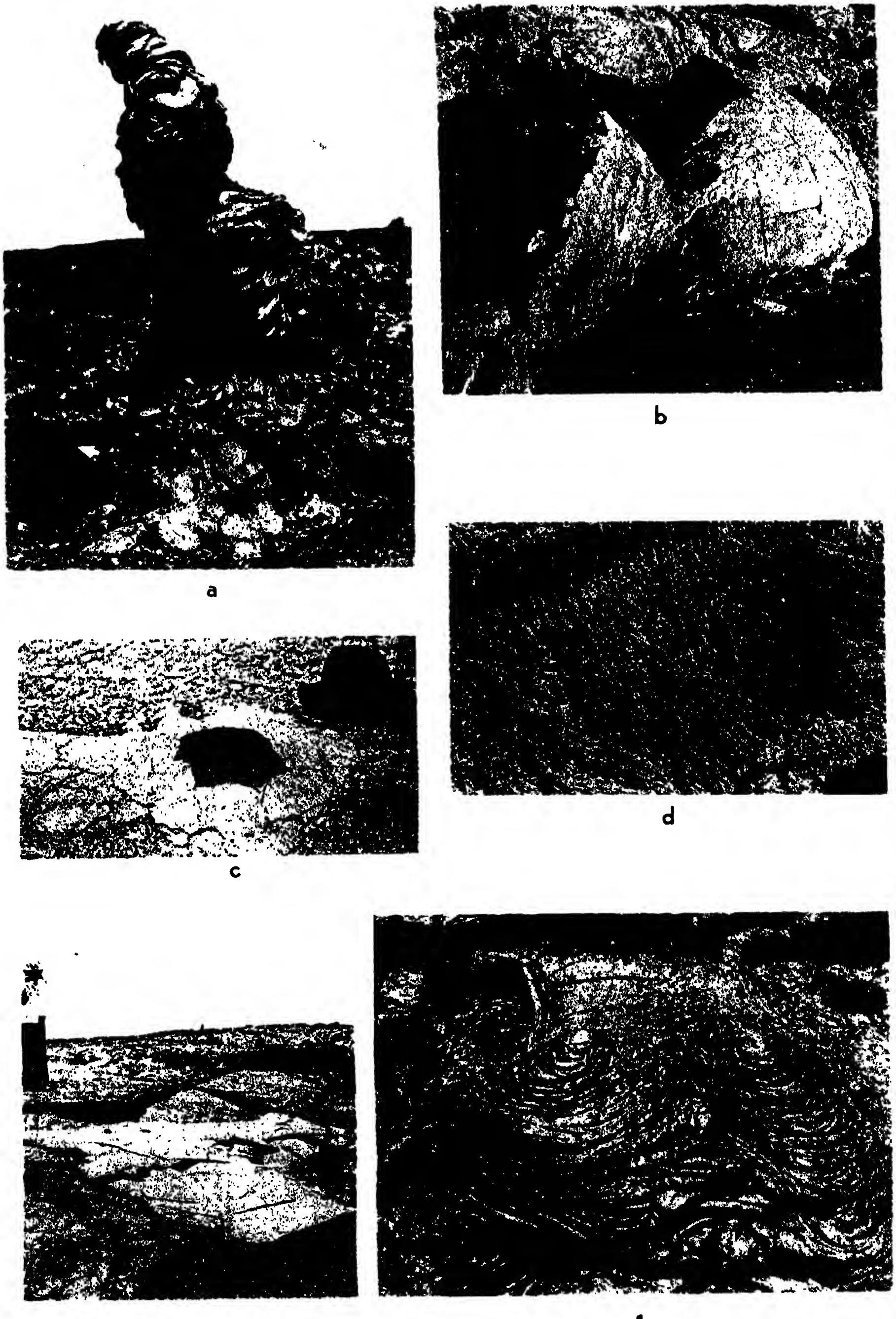
b. Marginal toe of shell pahoehoe, probably lava of 1894, which welled up crack in northeast Kilauea floor, the same trending northeast from Halemaumau. The frothy lava apparently withdrew down the crack after forming the crust shown. Spoken of as "balloon lava".

c. July 9, 1914, large blister in 1894 lava, Kilauea floor, showing tendency of pahoehoe skin to collect large gas chambers, the crusts of which form arches too flat to be self-supporting when cold and brittle.

d. West side of fresh aa flow at bank of stream January 1920, Kau Desert south of Mauna Iki. The arborescence shown is on the face of a step fault 2 feet high on the left bank of stream, the lava of which as congealed is shown in lower right corner of photograph. The arborescence appeared to be a feature of surface oxidation possibly accompanied by distributary flowing on the left wall of a gas-heated crack from which the left crust of the stream parted and shrank back, possibly with flaming gas coming up the crack. The mechanism suggests a possible control by crystallization of the sprouting phenomena of aa, where the action has been free from disruption of flowing. The color is the bright rusty red of ferric iron, and when pieces are broken out the under material is common vesicular basalt. In other words the arborescent sculpture shows no mineral texture different from the rock except that its surface is rusty.

e. A patch of highly glassy pahoehoe that had welled up as a puddle distinct from the ordinary pahoehoe on the Kilauea floor in 1894 lava. Photographed July 17, 1914. Later experience suggested that such wellings up of molten glass from caverns filled with active lava in a period of outflow might be due to sudden generation of steam from cascades of water during torrential rainfall. Such disturbance by sudden steam pressure of the equilibrium of a lava stream in a tunnel might force the stream locally to rupture its roof.

f. Solidified 1894 pahoehoe floor of Kilauea photographed July 9, 1914. Shows pahoehoe welling up a crack, streaming down in two bands medially clogged, forming festoons with side curtains, and with twisting wrinkles of skin developing ropy structure.



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SURFACE PATTERNS OF KILAUEA LAVA

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